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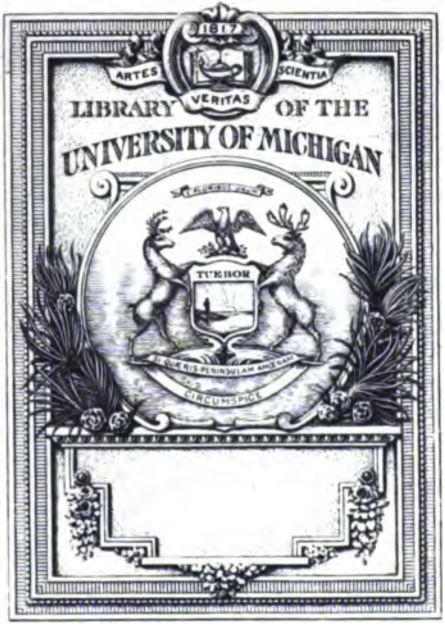
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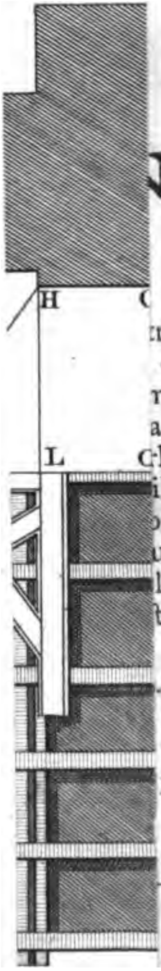

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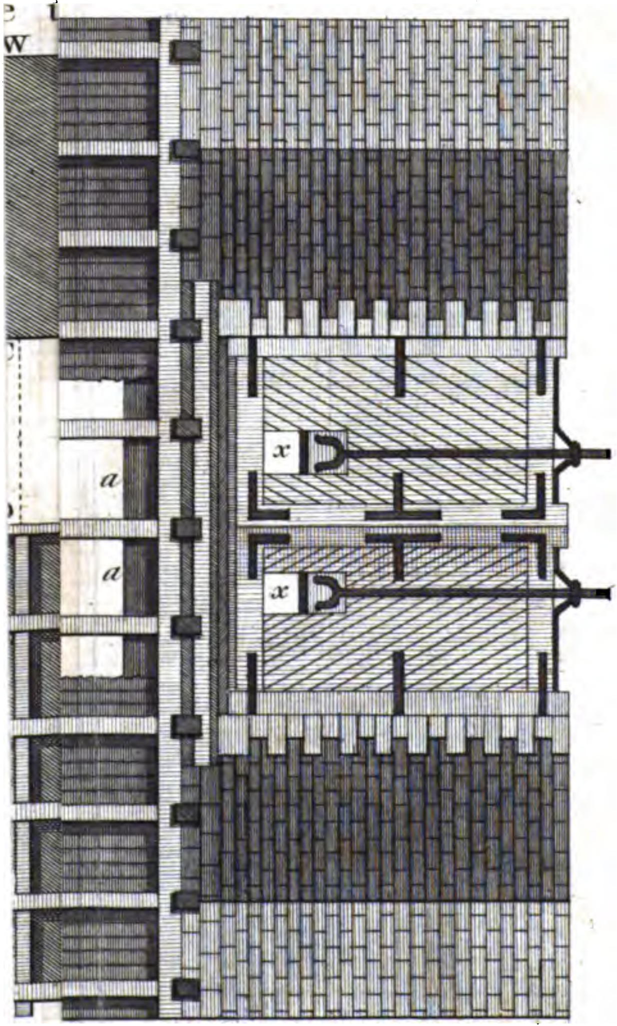
Plate XXVI.



Section Croſs-wiſe.

J Couse Sculp.

A

TREATISE

CONTAINING

The PRACTICAL PART

OF

FORTIFICATION.

In FOUR PARTS.

- I. The Theory of Walls, Arches, and Timbers, with ſeveral Tables of their Dimenſions.
- II. The Knowledge of the Materials, their Properties, Qualities, and the Manner of uſing them.
- III. The Manner of tracing a Fortreſs on the Ground, the making an Eſtimate, and executing the Works.
- IV. The Method of building Aquatics, as Stone-bridges, Harbours, Quays, Wharfs, Sluices, and Aqueducts.

Illuſtrated with Twenty eight COPPER PLATES.

For the USE of
The ROYAL ACADEMY of ARTILLERY
at *Woolwich.*

By JOHN MULLER,
Profeſſor of ARTILLERY and FORTIFICATION.

LONDON,
Printed for A. MILLAR, in the *Strand.*
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TO

HIS ROYAL HIGHNESS

GEORGE,

PRINCE of WALES.

SIR,

THE generous encouragement conſtantly given by your Royal Progenitors to thoſe who have endeavoured to make any Improvements in the uſeful arts and ſciences, makes me flatter myſelf that Your Royal Highneſs, who give ſuch early hopes of inheriting all their virtues, will be graciouſly pleaſed to honour the following treatiſe with Your Patronage.

My aim in publiſhing it, is to ſhew how fortreſſes may be built in the beſt and cheapeſt manner. I may venture to ſay, that a work of this kind has been hitherto wanting in the *Engliſh* language; and I may add, that the ſubject is moſt certainly of importance; experience having too often ſhewn the fatal effects which the neglect of the art of Fortification may produce, as well as the advantages ariſing to our prudent neighbours from the great encouragements they give to this branch of Knowledge.

Your Royal Grandfather, ever attentive to the public ſecurity and welfare, moſt graciouſly inſtituted the Royal Academy of Artillery for the inſtruction of young gentlemen in the Art of War. As it is my duty, ſo it has ever been my care, to facilitate their ſtudies: and if my labours ſhould be thought to deſerve Your Royal Highneſs's attention and approbation, it would be an inexpreſſible ſatisfaction to me, who think myſelf happy in every opportunity of ſhewing the profound reſpect with which I am,

SIR,

Your ROYAL HIGHNESS'S

moſt humble,

moſt dutiful,

and moſt obedient ſervant,

JOHN MULLER.

PREFACE.

WHEN a fortreſs is to be built, to chooſe ſuch a ſituation as will anſwer the intent in the beſt manner, to adapt the works properly, and to uſe no more than are neceſſary, to make from their plans and profils an eſtimate of the quantity of maſonry requiſite, and of the earth to be removed, to trace the plan on the ground, to lay the foundation in any kind of ſoil, to compleat the walls, ramparts, and all the military buildings, ſuch as draw-bridges, town-gates, powder-magazines, barracks, ſtore-houſes, cazemats, and ſally-ports; theſe are the ſubjects of Practical Fortification, and what we propoſe to treat of in the following work, together with the manner of building ſtone-bridges over large rivers, piers for incloſing harbours, wharfs, quays, ſluices, and aqueducts.

As no Treatiſe of this kind has appeared yet in Engliſh, I thought it would not altogether be uſeleſs to the public, if I ſhould give, in a plain and eaſy manner, the conſtruction and executive part of the works belonging to a fortreſs, and add whatever might contribute to the improvement of this uſeful art, ſuch as the theories contained in this work, which it has been my endeavour to render as general, and as ſimple as the nature of the ſubject will admit of, that they might extend to all the different caſes which may occur, and at the ſame time be with eaſe adapted to common practice.

It being of importance to know the proper thickneſſes of the walls which ſupport earth, ſo that they may be ſtrong and durable, yet not more ſo than is neceſſary; therefore this work begins with a general theory of them; which being deduced from the leaſt exceptionable principles, is applicable in all kinds of ſoils and caſes: for the common ſuppoſition made by ſome gentlemen of the Academy of Sciences at *Paris*, and by Mr. *Belidor*, that the natural ſlope of earth not ſupported by a wall forms an angle with the horizon of 45 degrees, is true in one particular kind of ſoil only. This is plain to reaſon, from the different tenacities of different ſoils, and may be verified by an eaſy experiment; which will ſerve likewiſe as a practical method for finding the angle formed by the natural ſlope of any kind of earth.

Make a bank of newly removed earth about ten or twelve feet high, and cut it vertically on one ſide; this bank being left ſtanding during eight or ten months in the dampeſt ſeaſon, will form the angle required. It is true, the particles of earth being heterogeneous, they will not form an even ſurface, therefore that angle will vary in different places; but as in practice no geometrical exactneſs can be obtained, nor is required; if that angle comes within five degrees of the real one, it is ſufficient; for that quantity, more or leſs, makes little difference in the thickneſs of walls, as may be ſeen in the table of general rules. Since then ſand cauſes a greater preſſure, and clay a leſs one, than common earth; to make the walls in each caſe of an equal ſtrength would endanger thoſe which ſupport ſand of falling down, and there would be more work than need be in thoſe which ſupport clay: beſides, as ſtone is ſpecifically heavier than brick, it is evident, that ſtone walls do not require ſo great a thickneſs as thoſe made of brick, yet the gentlemen mentioned before, have made no diſtinction between the one and the other in their theories.

As ſome of my readers may not underſtand algebra, which I have been obliged to uſe, in order to make the theory general; therefore to render this work uſeful to every reader, I have therefore added a table, containing general rules for finding the dimenſions of ſtone and brick walls of any height, according to the different angles made by the natural ſlope of earth with a vertical ſection, from 80 to 30 degrees for every 5 degrees interval, and according to the different ſlopes given to walls on the outſide. The natural ſlope of common earth making nearly an angle of 45 degrees, and being the caſe that moſt frequently happens in practice; I have computed four tables of dimenſions upon this ſuppoſition, two for ſtone walls, and two for brick ones, from ten to fifty feet high, with or without parapets: theſe tables contain the thickneſſes above and below in regard to the different ſlopes given to the walls on the outſide, together with the dimenſions of the counterforts; in order to ſave a builder the trouble of computing them himſelf, although it be very ſhort and eaſy.

Since fortreſſes are moſtly built at preſent with demi-revetements, that is, they are partly walled, and partly turfed on the outſide; I imagined that tables containing the dimenſions of this kind of walls would alſo be very uſeful, and ſo much the more acceptable to the reader, as no author has given any before; this was not owing to any belief that they were not uſeful, but rather to the difficulties in conſtructing them: for as the height of the walls and that of the earth above them, form an infinite number of caſes, to comprehend them all in a table would have been impoſſible: therefore the only thing that could have been expected was to give tables of their ratio's, as we have done.

That I might omit nothing uſeful in practice, I have given problems of all the different profils of walls which have hitherto been uſed upon various occaſions; and have compared the quantity of maſonry that each of them requires, in order to know which is preferable to the reſt; whereas the *French* authors, who are the only ones that have written upon this ſubject, have implicitly followed the profile of Mr. *Vauban*, as being univerſally uſed by all the engineers in *France*, without conſidering whether it might not be changed for another better adapted to the nature of the ſubject; whereby they have been reduced to the neceſſity of making their computations ſo very operoſe as they have done; on the contrary, I conſidered that as the ſections in the ſame kind of earth are always ſimilar, by making the profiles likewiſe ſimilar, the operations would become very eaſy; ſince the thickneſſes of thoſe walls which have the ſame ſlope would then be to their heights in a conſtant ratio.

I proceed next to the theory of arches, which is eſteemed one of the moſt difficult problems in mechanics;

chanics; for tho' ſeveral eminent mathematicians have attempted to ſolve it, yet in my opinion, not one has entirely ſucceeded; for whoever reads their performances of this kind, will find whenever their general equations are applied to any particular example, that nothing but abſurdities follow from ſome, and ſuch dimenſions from others, as by no means anſwer the purpoſe. Some of them have ſuppoſed that all the arch-ſtones were quite ſmooth and poliſhed, laid without any cement or mortar; and others, that the part of the arch between the key-ſtone and the hanches was as it were one continued ſtone, and the other part between the hanches and the ſpring of the arch, joined to the pier as if all together formed likewiſe one ſtone: but as both theſe ſuppoſitions are erroneous, and contrary to what happens in arches, it is evident, that the concluſions drawn therefrom cannot be juſt.

I have conſidered the preſſure of every arch-ſtone ſeparately, both in regard to its weight and the obliquity of its direction, and have ſuppoſed them to be laid in ſuch mortar, as is neither hard enough to make the arch like one continued ſtone, nor yet ſo ſoft as that they may ſlide with eaſe upon each other: from thence, and ſome known principles of mechanics, it is eaſily proved, that the ſum of the preſſures of all the arch-ſtones contained in half the arch is equal to the preſſure which the whole weight would make, were it placed in the center of gravity of half the arch; whereby the ſolution of the problem has been reduced to that of finding the centers of gravity in the ſeveral figures of which arches are compoſed, which centers are found in the moſt ſimple and eaſy manner that the nature of the ſubject will admit of; and the ſolution of the problem, whereby the thickneſſes of the piers are found, is contained in a very ſimple quadratic equation.

It has hitherto been imagined, though without any foundation, that an elliptic arch is weaker, and preſſes the piers with a greater force than a circular one: the reaſon which authors pretend to give for this ſuppoſition is, that all the joints of a circular arch when produced meet in the ſame point; from thence they erroneouſly conclude, that it is the ſtrongeſt; without conſidering that all low arches require leſs maſonry than thoſe which are higher, and that the increaſe of force againſt the piers ariſing from the obliquity of their directions, is diminiſhed more in proportion by the leſſer quantity of weight which they ſupport.

In the problems given of the ſeveral kinds of arches, it has been found, that the thickneſs of the piers are nearly the ſame in all arches of the ſame width; though thoſe of circular ones are rather greater than any others, but yet not ſo much as deſerves to be taken notice of. This appears alſo from the common principles of mechanics; ſince the higheſt arches, which are moſt loaded, have the directions of their preſſures leſs oblique; and on the contrary, the loweſt which are leaſt loaded, have the directions of their preſſures more inclined.

This being demonſtrated, many difficulties which often ariſe in the conſtruction of arches, are eaſily avoided: as for example, when a powder magazine built in the common manner would become ſo high as to be ſeen from without, it may be made with an elliptic arch: when cazemats, ſally-ports, or any other ſubterraneous buildings are to be built under low ramparts, and there is not a ſufficient quantity of earth to cover them if the arches were made circular, they may be made elliptic, or with arcs of circles. It is true, that elliptic arches may appear not ſo ſtrong in powder magazines as circular ones, and of conſequence, leſs able to reſiſt the ſhock of the ſhells thrown upon them: but if it be conſidered, that they are more curvated at their hanches where they are thinneſt, and that the middle of the arch, which is its weakeſt part, is ſufficiently covered by maſonry to apprehend any danger there; it will be found that the elliptic arches are full as ſtrong as the circular ones.

But the greateſt uſe of elliptic arches appears to be in the building of bridges, and they ſeem indeed to be the only ones that are proper for ſuch works: for when the arches are of a great width, the circular form raiſes the middle of the bridge too high above the ends, whereby the draught of heavy carriages becomes very great, neither does it appear ſo well to the eye, and requires much more maſonry than is neceſſary; to which may be added, that this great weight requires larger foundations for the piers, and often cauſes them to ſink when the ſoil underneath is not very hard and ſolid, as experience has ſufficiently ſhewn.

I do not know what can excuſe an architect, who makes uſe of circular arches in bridges, when it is known that they require ſo much more maſonry than is neceſſary; ſince an elliptic arch is as eaſily deſcribed upon boards with a ſtring about two points as a circular arch about one, neither is there any greater difficulty to trace the joints in one than in the other, nor in the making patterns for cutting the arch-ſtones: therefore the pretended difficulties which ſome builders alledge, to be met with in the conſtruction of elliptic arches, are frivolous and trifling, in compariſon to the many advantages they have over all others.

If the arches of *Weſtminſter-bridge* had been made elliptical, and ſo as that their heights had been two thirds of what they are now; then the great or middle arch, which is 76 feet wide, and 38 feet high, would have been reduced to the height of 25 feet four inches only, and the reſt in proportion; the quantity of maſonry contained in the arches would have been diminiſhed by one third, and the ſlope above, which is ſo conſiderably ſteep, and makes the bridge appear ſo diſagreeable to the eye, would have become quite eaſy.

In order to explain the ſeveral problems given for different arches, and to make their application plain and eaſy; I have given examples in numbers of every one, and for the ſake of ſaving trouble to the builders, I have computed a table of dimenſions for piers of powder magazines, being from 6 to 24 feet high, wherein the ſhock of the ſhells that may be thrown upon them has been conſidered: as theſe dimenſions agree very nearly with thoſe which Mr. *Vauban* has uſed in the conſtruction of ſeveral magazines; and theſe magazines have never failed in any ſiege, though many thouſands of ſhells have fallen upon them, as has been related; the reader may depend upon the dimenſions we have given in our table.

The third ſection contains the theory of timber, a ſubject of no leſs importance to an engineer than any of the former; ſince thereby he is informed, how to place every piece in its beſt poſition, and what dimenſions they ought to have, ſo as the whole frame ſhall be equally ſtrong in every part; without uſing more timber than is neceſſary. After having determined the proportion between the ſtrength of ſcantlings of the ſame or different ſorts of timbers, placed any how, and which have different dimenſions; I give ſeveral tables of dimenſions for girders, joiſts, principal rafters, and other pieces uſed in buildings, made of oak or fir, adapted to large and ſmall buildings; and from thence it is ſhewn, that the dimenſions given by architects, bear no juſt proportion to each other.

As moſt of our architects make the oaken ſcantlings of larger dimenſions than thoſe of fir, which are to ſupport the ſame weight; and as Mr. *Parent*, formerly of the Academy of Sciences at *Paris*, is ſaid to have made ſeveral experiments on the ſtrength of timber, and found that the ſtrength of fir ſcantlings is to the ſtrength of oaken ſcantlings of the ſame dimenſions, as 6 to 5: I was induced to make ſome experiments myſelf, in order to confirm, or ſhew the falſity of a ſuppoſition ſo improbable; by theſe experiments I found, that the ſtrength of the weakeſt oak I tried, was to the ſtrength of the beſt fir I could get, as 8 to 7, and by comparing the beſt of each ſort, as 3 to 2; which differs greatly from the practice of our architects, and the experiments made by Mr. *Parent.*

In regard to the practice which I have treated of in the ſecond and third parts of this work ſuch as forming a ſcheme for building a fortreſs, the manner of tracing the works on the ground, the preparing and diſtinguiſhing the materials, the laying the foundations in any kind of ſoil, the building the walls and ramparts, together with all the military buildings which fall under the direction of an engineer; we ſhall refer the reader for theſe to the table of contents; and only obſerve here, that nothing has been omitted which I imagined to be of any uſe to the young and unexperienced engineer.

The fourth and laſt part treats of aquatic buildings, a ſubject more copious, and no leſs neceſſary to be underſtood by an engineer than any yet mentioned: for few fortreſſes are now-a-days built but what are ſituated near navigable rivers, lakes, or the ſea, for the benefit of trade and navigation: conſequently bridges, harbours, ſluices, and aqueducts are immediately connected with them, and are to be built by the ſame engineer who directs the works of the fortreſs; for which reaſon, I have endeavoured to aſſiſt him as much as the ſhortneſs of the work will admit of.

This part begins with the deſcription of ſtone-bridges, where, after having treated of their ſituations, and other previous precautions to be taken before the dimenſions are fixed upon; I give a problem for determining the thickneſs of piers of any height, when the width of the arch is given; and from thence I have conſtructed a table, containing the thickneſſes of piers from 6 to 24 feet high for arches from 20 to 100 feet wide, which no author has yet done: It is true, Mr. *Belidor* has given a rule for finding the thickneſs of piers which are ſix feet high: but as this rule ſerves in one caſe only, and is deduced from practice, and not grounded on theory, nor any ſubſtantial reaſons; it is evident, that no great dependence can be had thereon. Then I deſcribe various methods for laying the foundations, either with batardeaus, coffers, or other contrivances, in different depths of water, and in any kind of ſoil; and alſo the manner of carrying on the work from the beginning to the entire finiſhing the bridge, with all the ſecurity and neceſſary precautions we could think of.

After this I treat of harbours, a ſubject of great importance in a trading nation like this, to preſerve not only the royal navy in ſtormy weather, but likewiſe afford an aſylum for merchantmen when in diſtreſs; though there have been ſeveral built in different parts of *Europe* in later times, yet we are very much in the dark in regard to a method whereby we may proceed in all kind of ſituations. Very few directors of theſe works have thought proper to communicate their proceeding to the public. Mr. *Belidor* is the only author who has written particularly upon this ſubject; but as in moſt parts of *France* ſtones are in great plenty, whereas they are generally very ſcarce in the greateſt part of this country; the method which the *French* chiefly follow can be but of very little uſe here: it is true, this author has given ſeveral others, that may be uſed in moſt ſituations, which I have taken care to inſert in this work, and have added ſuch others as I imagined might ſerve upon thoſe occaſions where his could not be applied.

I have endeavoured to be as particular as poſſible, in the preliminary enquiries to be made before a reſolution is taken to fix upon the ſpot of ground

If it be conſidered, that canals for navigation are made from one end of a country to the other, over hills and valleys by means of ſluices and aqueducts; that harbours are formed and cleared from the ſand and ſhingle driven in by the water; low and marſhy lands dried and made arable, as likewiſe dry and barren lands ſupplied with a proper moiſture to make them fruitful; countries are defended againſt a powerful enemy by forming inundations; towns ſupplied with water: and if to this we add, the excellent uſe of ſluices in the attack and defence of places, ſo well deſcribed by Mr. *Belidor*, whereby a fortreſs may be made almoſt impregnable; whoever conſiders all theſe things, will find, that no works directed by an engineer, require a more extenſive knowledge, both in theory and practice.

I have endeavoured throughout the whole work to be as diſtinct as I could, in order to make the ſubject plain and eaſy; but as no improvements can be made in any branch of learning without the help of theory, I fear that many of my readers will not underſtand the moſt eſſential parts of this work, which it was not in my power to treat of otherwiſe; I would therefore adviſe the learner to begin to ſtudy my *Elements of Mathematics*, which were compoſed chiefly for military gentlemen, and to ſerve as an introduction to works of this kind.

As I am ſenſible, that for want of being thoroughly acquainted with the *Engliſh* Language, many grammatical errors are to be found in this work, notwithſtanding all the poſſible care that has been taken; I hope for the reader's indulgence in this reſpect.

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ERRATA.

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9.	4.		*dele* ;
10.	31.	being	is
27.	4.	;	:
29.	1.	out	but
31.	28.	CQ of all	of all the CQ's
36.	18.		*dele* good
37.	12.	ſupport [them	to ſupport [than
47.	25.	is	are
60.	4.	of the	the
ibid.	8.	be given	to be given
ibid.	20.		*dele* becauſe
63.	1.		*dele* and
64.	14.	and	who
65.	14.	depend	depends
66.	21.	exhilerated	exhauſted
79.	29.	that	that of
80.	13.	to the	, to the
91.	20.	of	of them
93.	13.	expends	expands
117.	27.	being	is
148.	10.	95521	95591
ibid.	19.	many	too many

Pag.	*Lin.*	*For*	*Read*
178.	32.	lower	tower
206.	1.	threſhold	ſelle
ibid.	9.		Plate XIV.
207.	26.	XV.	XIV.
218.	10.		*del.* are
220.	13.	but	: but

Addition to page 240, line 3, from the bottom, before *Divide the breadth*; divide the breadth of the building into 8 equal parts, and make the perpendicular height three of them: and for ſlate and plain tiles,

Pag.	*Lin.*	*For*	*Read*
260.	10.	large	laſt
261.	18.	ſwater wells	water ſwells
289.	1.	A S	B S
ibid.	10.	A B	B O
296.	10.	inches	24 inches
ibid.	10.		*dele* 24 [theſe
298.	1.	theſe	the length of
Tables		1ſt and 2d	profil the 2d
		3d and 4th	profil the 3d

A

TREATISE

CONTAINING

The PRACTICAL PART

OF

FORTIFICATION.

SECT. I.

The THEORY *of* WALLS.

HAVING given the elementary part of fortification in a former volume, we deſign in this to treat of the practice, that is, when a fortreſs is to be built, to ſhew how the ſituation is to be examined before the plan is made, and the figure, or form of the works to be uſed, fixed upon; ſo as to anſwer our expectation both in reſpect to the expences and the nature of the ſituation; to trace the plan on the ground; to compute the quantity of maſonry it will contain, and the quantity of earth to be removed; the nature and quality of the materials, and how to prepare them; to lay the foundation, whether it be on rock, moveable ſand, or on any other kind of ſoil; to raiſe the ramparts; to build the gate-ways, powder magazines, ſtore-houſes, cazemats and other under-ground works; in ſhort, to give the principles and rules of every thing relating to military architecture; in the plaineſt and, at the ſame time, the moſt compleat manner that can be deſired.

As the greateſt expence which attends the execution of ſuch works is occaſioned by the quantity of maſonry required, it is of no ſmall importance to know the proper thickneſſes of the walls in reſpect to their height, ſo as they may ſufficiently reſiſt the preſſure of earth they ſupport, and at the ſame time there may be no more work uſed than is abſolutely neceſſary, and yet to make it ſtrong and durable, which is what we intend to treat of in this firſt ſection.

Mr. Vauban was the firſt engineer who has given any rules for finding the dimenſions of ſtone walls which ſupport earth. This he did by means of one general profil, expreſſing the thickneſs, from one of ten feet to eighty feet high; and as he had more experience than any other engineer, having been imployed in the works of above 150 places, a great number of which he built new, he would certainly have been the beſt qualified perſon, to give ſuch rules, had his knowledge in the mathematics and natural Philoſophy been equal to his experience. But for want of this knowledge, ſo little regarded by moſt practical engineers, and yet abſolutely neceſſary for making any improvement, ſome of his profils have been found too ſtrong and others too weak.

Some gentlemen of the royal Academy of ſciences at Paris, have endeavoured to deduce the theory of walls, from mechanical principles, in which they have ſo far ſucceeded, as to lay a proper foundation for others to go upon: but not being ſufficiently acquainted with the practice, they were obliged to have recourſe to Mr. *Vauban's* general profil, whereby their computations became very tedious and operoſe.

After them Mr. *Belidor* undertook to explain this theory in a more ample manner, in his book called *La ſcience des Ingenieurs*, in order to render its application to practice more eaſy: but as he followed nearly the ſame method as the former gentlemen, and confined himſelf likewiſe too much to Mr. *Vauban's* general profil, his operations are become not much ſhorter than the former: but to make the application to practice eaſy, he has given two tables, the one for walls with parapets, and the other for walls without parapets, from ten to a hundred feet high.

After having conſidered the ſubject with attention, we found that if the profils were made ſimilar to each other, the work would be much ſhortened. And this is found to be agreeable to the nature of the preſſure which the earth makes againſt the walls. For the ſections of the ſame kind of earth terminated by the ſlope it would form, if it were not ſupported, will form ſimilar triangles, which therefore are as the ſquares of their homologous ſides, that is, as the ſquares of the heights of the walls; conſequently the profils being likewiſe made ſimilar and proportional to that height, the preſſure and the reſiſtance, being made equal in one, will alſo be equal in all the reſt.

Mr. *Belidor* and theſe gentlemen, ſuppoſe the angle made by the natural ſlope of earth to be 45 degrees, which is one caſe only; for the ſlope made by clay or loam, will certainly be leſs, than that made by any other kind of earth; and it is plain, that theſe ſlopes vary according as the tenacity of the particles is greater or leſs: and therefore the tables given by Mr. *Belidor* are not ſufficient.

They have likewiſe conſidered ſtone-walls only, and as the greateſt part of our fortreſſes are built with bricks, which are ſpecifically lighter than ſtone, it is neceſſary to have particular rules for them, different from the others. And as moſt ramparts are at preſent built with demi-revetements, their dimenſions require likewiſe particular conſiderations: ſo that conſidering the whole extent of this theory, it will be found that all that has been ſaid by the former authors, is no more than a foundation for others to go upon.

Of COUNTERFORTS.

IN building walls that are to ſupport earth, buttreſſes are made behind them at certain diſtances from each other, which are not ſeen, as being covered with earth; they are made in view to ſtrengthen the wall againſt the preſſure of earth, and to ſave expences; for by this means there is no occaſion to make the walls ſo thick as they otherwiſe muſt be. Theſe buttreſſes, are called *Counterforts*, in fortification, and are made of various forms.

Plate I. Fig. 2. Suppoſe the trapezium ABCD to repreſent the ſection of a wall without parapet; then the rectangle DF repreſents the elevation of the Counterfort, which is generally as high or within a foot, as the wall, and the baſe DG the length; and if we conſider the plane of the wall; where KLMN, repreſents the baſe of the Counterfort, and NP, their diſtance from each other, which may vary at pleaſure.

Mr. *Vauban* made the baſe KLMN of the counterforts always broader at the root KN than at the tail LM, in the conſtant proportion of three to two; and the diſtance from the center of one to that of the next, 18 feet: On the other hand, Mr. *Belidor* would have them made the contrary way, that is, narrower at the root KN than at the tail LM in the ſame inverſe proportion of two to three; becauſe the center of gravity of the counterfort, being thereby farther from the wall, will ſupport a greater weight, than thoſe made by Mr. *Vauban*; they are beſides not ſo eaſily deſtroyed by cannon, when the wall is beat down, and ſo keep better up the earth. But as he imagined that the engineers would hardly change an old eſtabliſhed practice, for any other ever ſo advantageous; he computed his tables according to Mr. *Vauban's* profil.

We, on the contrary, make the baſe of our counterforts rectangular, partly becauſe our engineers make them ſo, and becauſe they are very near as ſtrong as thoſe made by Mr. *Belidor*; they likewiſe bind better with the wall, and the workmanſhip is cheaper and eaſier; ſo that in the mean, they are better than thoſe of any other form.

Inſtead of placing the counterforts at the ſame diſtance, whether the wall is high or low, as Mr. *Vauban* does, we make their thickneſs KN to their interval NP always in the conſtant ratio of unity to three, and their length KL or DG, one fourth of the height DC of the wall. From this diſpoſition of the counterforts, the profils become ſimilar, and their thickneſs BC above is in a conſtant ratio, with the height DC, when the ſlope AB remains the ſame; as will be ſeen hereafter; whereby the operations become extremely eaſy. And this rule is agreeable to the preſſure of the earth, which we have ſhewn above to be ſimilar in the ſame ſort of ſoil.

In a wall of ten feet high, the counterforts, according to Mr. *Vauban's* general profil, are 3 feet thick and at 15 feet diſtant from each other; and in a wall of 80 feet, their thickneſs is 10 and diſtance but 8; and therefore his counterforts are too far diſtant in low walls and too near in high ones; whereas ours may be placed farther from or nearer to each other, according as it is convenient in practice, provided the proportions mentioned above are obſerved.

It may be obſerved, that the longer the counterforts are, the greater force they have to reſiſt the preſſure of the earth; but when they are made ſo narrow, they do not bind ſo well with the wall; for which reaſon, I would make their thickneſs never leſs than half their length. For inſtance, in a wall of 40 feet high, the length of the counterforts will be 10 feet, according to the proportion mentioned before: their thickneſs ought in my opinion, to be no leſs than 5 feet, and then their diſtances from each other will be 15 feet; but in a wall of ten feet high, their length will be two feet ſix inches; and their thickneſs ought to be two feet; then their interval will be ſix; whereas if they were made thinner, they would ſtand too cloſe to one another.

In order to have a clear idea of what follows in regard to the theory of walls, it is neceſſary to explain the ſuppoſitions, on which its veracity depends. Thus we ſuppoſe that if new-made earth, ſuch as in ramparts, was not ſupported by a wall, the particles would looſen from each other by the dampneſs of the weather, and tumble down ſo as to make a ſlope nearly in a plane ſurface, which plane is called the natural ſlope of the earth; and is ſuppoſed to have always the ſame inclination in the ſame ſort of ſoil.

The ſecond is, that the wall is ſo well cemented, as if it were made of one ſingle ſtone, as far as its foundation, ſo that, if a ſufficient power was applied to any part of it, it would in overturning break off near the foundation, and would turn in the ſame manner as if it was compoſed of one ſtone only.

The firſt of theſe ſuppoſitions may be proved in this manner; ſince whatever obliquity is required for one particle to tumble down, the ſame will alſo be required for any other of the ſame weight and tenacity, and therefore the ſum of all the particles tumbled down, will form a plane ſurface nearly, which has always the ſame inclination in the ſame ſort of ſoil, but will vary according as the ſoil has a greater or leſs tenacity. For example, ſand will form a greater ſlope than common earth, and this a greater than loam or clay.

It may be ſaid, that all the particles of the ſame ſort of ſoil have not the ſame magnitude, as may be ſeen diſtinctly in ſand, and therefore what we have ſaid is not abſolutely true: but though it is impoſſible to determine

mine this ſubject according to a mathematical ſtrictneſs, yet it is ſufficiently exact for common practice, where ſo great a nicety is not required, nor neceſſary.

As to the ſecond ſuppoſition, if we conſider that the wall is always built a twelve month, or ought to be ſo, before the earth is laid againſt it, it has time to dry well, before any preſſure is made againſt it; beſides ſmall branches of wood are mixt with the earth to leſſen its preſſure: and tho' the wall is joined as firmly to its foundation as in any other part, yet this is advantageous to the reſiſtance of the wall; and the ſuppoſed equilibrium, between the momentums of earth and the wall, is not ſtrictly true, nor ought it to be ſo; or elſe the wall would ſoon tumble down, by the leaſt accident that would happen.

As we do not confine ourſelves, to any particular angle made by the natural ſlope of earth in the enſuing work; we are obliged to repeat here ſome of the Problems out of our Elements of Mathematics.

PROBLEM I.

To find the preſſure of earth repreſented by the triangle CDT, *againſt the profil* ABCD, *of a wall, in a direction perpendicular to the vertical line* DC. Plate I. Fig. 1.

AS the profil ABCD, and the triangle DCT, repreſent the baſes of ſolids which have the ſame altitude, the weights of theſe ſolids will be proportional to their baſes; for which reaſon we ſhall conſider the areas of theſection ABCD, and of the triangle DCT, as ſo many weights, which are proportional to them. Since the ſum of the momentums of all the parts is equal to the momentum of the whole weight re-united into its center of gravity by art. 5.67 of our Elem.

It

It is evident that the weight of the triangle DCT, may be conſidered as re-united into its center of gravity S, and the deſcent of that center, when the triangle ſlides along the inclined plane, will be that by which its force againſt the wall muſt be eſtimated. If therefore SR be drawn perpendicular to the ſide DC of the wall; the whole preſſure may be conſidered as acting againſt that point R.

Now becauſe the area of the triangle DCT, is equal to $\frac{1}{2}$ DC × CT; if we call T the action of the weight in the direction parallel to the inclined plane DT; and W the part acting in the direction SR perpendicular to DC: we have DT : DC : : $\frac{1}{2}$ DC × CT : T; by art. 499 of our Elements; and DT : CT : : T : W, by art. 501: and the compound of theſe proportions gives $\overline{DT}^2$: DC × CT : : $\frac{1}{2}$ DC × CT : W. Conſequently the angle CDT being given, the preſſure W will be given likewiſe.

COR. I.

Hence if the height DC of the wall be called a, DT unity, and CT $= s$: then will $W = \frac{1}{2} ssaa$, by the laſt proportion; and becauſe the action along the inclined plane DT, is retarded by the coheſion of the parts, and it has been found by experiments that a body ſliding along a ſmooth plane, requires one third of its weight to move it; therefore this expreſſion ought to be diminiſhed in the ratio of 3 to 2, in order to get the true preſſure: Again, the ſpecific gravity of ſtone is to that of earth as 3 to 2; ſo that if we will compare the weight of the triangle DCT of earth with the weight of ſtone; the expreſſion muſt be reduced alſo in that ratio: that is, the value of W muſt be reduced in the ratio of 9 to 4, in order to get $\frac{2}{9} ssaa$ for the true preſſure.

COR. II.

COR. II.

Becauſe the line S R, is parallel to the baſe A D; DR will expreſs the diſtance of the direction S R of the preſſure againſt the wall from the baſe, or the point; fix A, about which the wall muſt turn in order to be overſet; and ſince D R is $\frac{2}{3}a$, by art. 425. the product of the weight $\frac{2}{9}ssaa$, multiplied by the diſtance $\frac{2a}{3}$; gives $\frac{4}{27}ssa^3$, for the momentum of the earth's preſſure.

NB. It may be obſerved that D T is to C T, as the radius is to the ſine of the angle C D T; and therefore, s expreſſes the ſine of that angle, when the radius is unity.

PROBLEM II.

To find the thickneſs BC *above of a ſtone wall* ABCD, *ſo as to reſiſt the preſſure of the earth* CDT.

Draw BE perpendicular to the baſe A D; and let the weights Q, P, be ſuſpended in the centers of gravity of the triangle A B E, and the rectangle E C, and to be proportional to their areas reſpectively.

Now becauſe the preſſure of the earth endeavours to overſet the wall in the direction S R or D A, whilſt the weights Q, P, retain it in a direction perpendicular to A D: the ſum of the momentums of the weights Q, P, muſt therefore be equal to the momentum of the earth's preſſure, in caſe of equilibrio. Hence, if B C or E D $= x$, and A E $= na$; the letter n expreſſing an indetermined but conſtant quantity; then will Q $= \frac{1}{2}naa$, P $= ax$; and as the diſtances of the weights Q, P, directions from the point A, are $\frac{2}{3}$ A E, A E $+ \frac{1}{2}$ E D; that is, $\frac{2}{3}na$, $na + \frac{1}{2}x$; therefore $\frac{1}{3}nna^3$ will be the momentum of the weight Q, and $naax + \frac{1}{2}axx$,

$\frac{1}{2}axx$, that of the weight P: the ſum of theſe two momentums being made equal to $\frac{4}{27}ssa^3$ the momentum of the earth, and both ſides divided by $\frac{1}{2}a$, gives $xx + 2nax + \frac{2}{3}nnaa = \frac{8}{27}ssaa$; by adding $\frac{1}{3}nnaa$ to both ſides, the firſt will be a perfect ſquare, whoſe root multiplied by 9, and the other ſide by 81, is $9x + 9na = a\sqrt{24ss + 27nn}$.

N. B. Mr. *Cotes*, in his Hydroſtatic lectures, page 61, ſays that the ſpecific gravity of ſtone is to that of bricks as 2.5 to 2; that is, as 5 to 4. If therefore we increaſe the firſt term $24ss$, under the radical ſign in the ratio of 4 to 5, we ſhall have $9x + 9na = a\sqrt{30ss + 27nn}$, for the equation which determines the thickneſs above of brick walls.

For example, if the baſe of the wall's ſlope is one fifth of its height, and the ſlope of earth makes an angle of 45 degrees; then will $n = \frac{1}{5} = .2$, $nn = .04$, and $ss = .5$: whence multiplying 24 by .5 and 27 by .04 and extracting the ſquare root of the ſum 13.08, we get 3.6167, from which ſubſtracting 1.8, and the difference divided by 9 gives $x = .2018a$, or $x = \frac{1}{5}a$ nearly in ſtone walls. But if 30 be multiplied by .5, and added to 1.08; the ſquare root of 16.08, will be 4.009 nearly; from which ſubſtracting 1.8, and dividing the difference by 9, we get $x = .245a$ nearly in brick walls.

PROBLEM III.

To find the thickneſs above, of ſtone walls which have counterforts, ſo as to reſiſt the preſſure of the earth. Fig. 2.

Becauſe the length DG of the counterforts being a fourth part of the height DC; the area DF will be $\frac{1}{8}aa$, and AD + $\frac{1}{2}$DG, that is, $x + na + \frac{1}{8}a$, will be the diſtance of its direction from the point A;

therefore $\frac{1}{4}aax + \frac{1}{4}na^3 + \frac{1}{32}a^3$, will be the momentum of the counterfort: but as there is an interval between them, and therefore is too much by that interval, or as but one part in four is taken up by the counterforts; this momentum muſt be divided by 4, in order to have $\frac{1}{16}aax + \frac{1}{16}na^3 + \frac{1}{128}a^3$, for the true momentum; which being added to that of the wall found in the laſt problem, and their ſum being made equal to that of the earth, when divided by $\frac{1}{2}a$, gives, $xx + 2nax + \frac{1}{8}ax + \frac{2}{3}nnaa + \frac{1}{64}aa = \frac{8}{27}ssaa$: if we add $\frac{1}{3}nnaa - \frac{.75}{64}aa$ to both ſides, the firſt will be a perfect ſquare, and the ſecond reduced under the ſame denomination, whoſe common denominator is 81 × 64; then the firſt ſide multiplied by its root 72, gives $72x + 72na + 4.5a = a\sqrt{1536ss - 60.75 + 1728nn}$ for the general equation which determines the value of x in ſtone walls: But if we increaſe the firſt term $1536ss$ under the radical ſign, in the ratio of 4 to 5, as has been ſhewn in the laſt problem, we get $72x + 72na + 4.5a = a\sqrt{1920ss - 60.75 + 1728nn}$, for the general equation which determines the value of x, in brick walls.

Hence it is manifeſt, that when the ſine s, and the value of n are known, the thickneſs above x, of the wall, will be always expreſſed by parts of a, the height of the wall; and from thence, general rules may be found for all the different ſlopes that commonly are given to walls, and for any angle the ſlope of earth makes with the vertical line DC, as will appear by the following examples.

Let the baſe AE of the ſlope be one fifth of the height DC, and CDT an angle of 45 degrees: then will $n = \frac{1}{5} = .2$, and $ss = \frac{1}{2}$; theſe values being ſubſtituted into the firſt equation gives 776.37 for the quantity under the radical ſign, whoſe ſquare root is $27.863a$; from which ſubſtracting the ſum $18.9a$, of the two known terms, and dividing the difference by 72, we get $x = .1245a$, or $x = \frac{1}{8}a$ nearly in ſtone walls.

But if we ſubſtitute the values of ss and n, into the ſecond equation, we get 968.37 for the ſum of the terms under the radical ſign, whoſe ſquare root is 31.118a, from which ſubſtracting the ſum 18.9a, of the two known terms, and dividing the difference by 72, we get $x = .169\,a$, in brick walls

If the baſe A E of the ſlope is one ſixth, and the angle C D T, 45 degrees: then will $n = \frac{1}{6}$, $ss = \frac{1}{2}$; theſe values being ſubſtituted into the firſt equation gives 755.25 for the ſum of the terms under the radical ſign, whoſe ſquare root is 27.481a, from which ſubſtracting the ſum 16.5a of the two known terms, and dividing the difference by 72, we get $x = .153a$, in ſtone walls.

But if the ſame values of n and ss, are ſubſtituted into the ſecond equation, we get 947.25, whoſe ſquare root is 30.777a, from which ſubſtracting the ſum 16.5a of the two known terms, and dividing the difference by 72, gives $x = .198a$, in brick walls.

Again ſuppoſe the angle of the ſlope DT to be 30 degrees, then will $s = .5$; and $ss = .25$: theſe values being ſubſtituted into the firſt equation, give 384, for the firſt term under the radical ſign, and by ſubſtituting that value in the ſecond equation, we get 480 for that term.

Now if $n = .2$; we get 392.37 for the ſum of the terms under the radical ſign, whoſe ſquare root is 19.808, and hence $x = .013a$, nearly in ſtone walls; and in brick walls, we get 488.37 for the quantity under the radical ſign whoſe ſquare root is 22.099, and hence $x = .044\,a$ nearly.

Becauſe the ſum of the ſquares of the ſine and coſine of any angle is equal to the ſquare of the radius; if we ſubſtract the ſquare .25 of the ſine of 30 degrees, from the ſquare of the radius or unity, we ſhall have .75 for the ſquare of the ſine of an angle of 60 degrees.

Whence, ſubſtituting this value into the firſt equation, we ſhall have 1152 for the firſt term under the radical ſign, and by ſubſtituting the ſame value into the ſecond, we get 1440 for the firſt term under the radical ſign.

Now if $n =. 2$; then will 1160.37 be the ſum of the terms under the ſign, whoſe ſquare root is 34.064, and hence $x =. 211a$, in ſtone walls, and 1448.37, will be the ſum of the terms under the ſign, whoſe ſquare root is 38.057: and therefore $x =.266a$, in brick walls. When the ſlope of earth D T makes any other angle, the operations become more tedious; and in that caſe the values of s, are to be taken out of the tables of natural ſines; and it will be ſufficient to take only the three firſt numbers.

But to ſave the trouble to the practical engineers, we have computed the values of x, when the ſlope is $\frac{1}{5}$, $\frac{1}{6}$, $\frac{1}{7}$, $\frac{1}{8}$; for both ſtone and brick walls; and when the ſlope D T of earth makes an angle from 30 to 80 degrees, for every 5 degrees, which we imagine to be ſufficient, as may be ſeen in the following table, where the fractional numbers in the firſt horizontal column expreſs the ratio of the baſe A E of the wall's ſlope to the height of the wall; the firſt vertical column ſhews the angles which the ſlope of earth makes with the vertical line D C: and the other numbers give the ratio of the thickneſs of the wall; or the values of x, to its height, which numbers are all decimals.

Example, If the baſe AE of the ſlope is one fifth of its height, and the angle C D T, is 45 degrees; then the number oppoſite to 45 and under $\frac{1}{5}$, is 125, which being multiplied by the height of the wall, ſuppoſe 30 feet, gives 3.750, or 3 feet 9 inches; ſuppoſe the angle C D T, to be 60 degrees, and the baſe of the ſlope one fifth; then the number 211 oppoſite to 60 and under $\frac{1}{5}$, being multiplied by the height of the wall 30 feet, gives 6.330 or 6 feet 4 inches nearly.

N. B. It muſt be obſerved once for all, that we always take the neareſt number in all our computations. Thus if the fourth decimal is either 5 or above, we always increaſe the third by unity; the ſame thing is to be obſerved in regard to inches: for in the laſt example .33, multiplied by 12, gives 3.96 inches, which is 4 inches nearly.

GENERAL RULES

Ang.	For Stone walls. $\frac{1}{5}$	$\frac{1}{6}$	$\frac{1}{7}$	$\frac{1}{8}$	For Brick walls. $\frac{1}{5}$	$\frac{1}{6}$	$\frac{1}{7}$	$\frac{1}{8}$
80°	275	304	326	342	338	368	389	406
75	265	292	316	332	327	356	378	395
70	250	280	301	317	311	340	362	378
65	235	262	283	299	290	320	342	358
60	211	239	256	277	266	296	314	333
55	191	214	235	251	238	267	288	304
50	153	185	202	221	205	230	251	271
45	125	153	173	189	169	198	219	235
40	089	117	137	153	130	159	179	195
35	052	079	093	114	087	116	134	152
30	013	038	057	072	044	071	090	106

As the baſe of the ſlope is never leſs than one eighth nor greater than one fifth of the wall's height; we thought it needleſs to carry theſe general rules any farther, which however may be done by means of the two preceeding equations, whenever it is thought neceſſary.

To find the general rule for any intermediate angle, ſay: As 5 degrees is to the difference between the given angle, and that next to it in the table, ſo is the difference between the numbers in the table oppoſite to the angles next below and above the given angle; the fourth term added to the neareſt number if above it, or ſubſtracted if below, gives the number ſought. Thus the angle being 53: ſubſtract it from 55, ſubſtract the number 153 of 50 from the number 191, which gives 38. Then ſay 5 : 2 : : 38 : 15; and 15 ſubſtracted from the number oppoſite to 55, which is 191 gives 176 for the number ſought.

The firſt and ſecond tables have been computed from the general rules, when the ſlope of earth makes an angle of 45 degrees, which is moſt commonly the caſe in a middling ſoil, and is what Mr. *Belidor* and others have ſuppoſed; ſo that if any error ſhould have been committed in theſe tables, they may be corrected by the laſt rules, and if the height of a wall, not expreſſed in theſe tables, ſhould be given, whoſe thickneſs above being required, it may be found. Thus if the given height be 35 feet, and the ſlope one fifth; multiply that height by 125, which gives 4.375 feet or 4 feet and 4.5 inches for the thickneſs required in a ſtone wall.

The thickneſs near the foundation, is found by adding the baſe of the ſlope to the thickneſs above; thus when the baſe of the ſlope is one fifth, and the wall 30 feet high, then one fifth of 30 is 6, to which add the thickneſs above 3 feet 9 inches, and the ſum 9 feet 9 inches will be the thickneſs required. It is to be obſerved that the length of the counterforts, in theſe tables, is always one fourth of the wall's height as has been mentioned before, and their thickneſs is to their interval as unity is to 3.

PROBLEM IV.

To find the thickneſs of walls which have parapets, according to the third profil. Fig. 3.

In walls with parapets, the ſlope AB of the wall is always terminated by the cordon B, within four feet of the top F, and the upright wall BFHI, never exceeds three feet in thickneſs; and the part HI, is always terminated by the line DC produced, when BC does not exceed three feet.

If the upright part I F of the wall was ſufficient to reſiſt the preſſure of the earth, above the line B K produced; there need be no other tables than thoſe already given; but as this is not the caſe; the preſſure of the earth above the line B K ſhould be computed as well as the reſiſtance of the wall I F, in order to have the true ſolution of the problem: But this would make the work more tedious, than is neceſſary in practice, and therefore we ſhall eſtimate this force in an eaſier manner, which anſwers full as well.

Suppoſe the wall A B C D to be carried up quite to the top F, and ſo as to be ſufficiently ſtrong to reſiſt the preſſure of the earth, and from thence the thickneſs at B C is to be found; then I ſay, that the ſtrength of the whole wall will be ſufficient to reſiſt the preſſure of the earth.

For the earth above the line B C, extends not above 18 feet, that is very little farther than the parapet F N reaches; and therefore the part I F of the wall will nearly be ſufficient to reſiſt the preſſure of that earth; and as B C is more than it ſhould be, were the earth no higher than B C, it is plain that the wall thus determined will reſiſt the preſſure of the earth more than is ſufficient: beſides this agrees perfectly well with Mr. *Vauban's* profil of 30 feet high, that has been uſed in above 50 places without having ever failed.

Now becauſe the height B E is to the baſe E A of the ſlope as the height BF, or 4 feet, is to the difference between the thickneſs at B and that at F; that is, as A E is $= na$, B E $= a$; we have $a : na :: 4 : 4n =$ to the difference required, which therefore being added to the thickneſs at F, found in the preceding tables, anſwering to the height E F, gives the thickneſs B C required.

GENERAL RULES.

If the baſe A E *is one fifth of the height,* B E; *then*

4 n *becomes* .8 *or* 9.6 *inches, which is to be added to the thickneſs in the ſecond Column.*

If A E *is one ſixth of* B E, *then will* 4 n *become* $\frac{4}{6}$ *or* 8 *inches, which is to be added to the thickneſs in the fourth column.*

If AE *is one ſeventh of* B E; *then will* 4 n *become* $\frac{4}{7}$ *or* 7 *inches nearly, which is to be added to the thickneſs in the ſixth column.*

Laſtly, If AE *is one eighth of* B E; *then* 4 n *becomes* $\frac{4}{8}$, *or* 6 *inches; which is to be added to the thickneſs in the eighth column.*

By theſe general rules the third and fourth tables have been conſtructed, the lengths of the counterforts in the tenth column, are the fourth part of the total height; though they are never carried higher than the cordon: But it muſt be obſerved, that the numbers in the firſt column, expreſs the heights, from the foundations to the cordon B only; becauſe the height B F, of the upright part is always 4 feet in all walls whatſoever, that have parapets.

To ſhew by a few examples how the preceding general rules are applied; we ſhall ſuppoſe the height E B of a ſtone wall to be 30 feet, and the baſe A E one fifth of that height: then adding 4 feet to 30 we get 34 feet for the total height E F; and the thickneſs found in the ſecond column of the firſt table, anſwering to 34 feet, being 4 feet 3 inches; to which adding 9.6 inches by the firſt rule, gives 5 feet and .6 of an inch, for the thickneſs required. Mr. *Vauban* makes this thickneſs 5 feet; ſo that ours does not exceed his but by half an inch nearly.

If a ſtone wall is 24 feet high, and the baſe of the ſlope one ſixth; then 4 feet added to 24 gives 28 feet; and the thickneſs anſwering to this height in the fourth column of the firſt table is 3 feet 6 inches; by adding 8 inches according to the ſecond rule; then the ſum 4 feet 2 inches will be the thickneſs at B C required.

Thus we have given tables not for ſtone walls only, but likewiſe when they are built with brick; and their conſtructions are deduced from the moſt ſimple principles, and at the ſame time the moſt general that could have been thought of: and thoſe general rules we have given for the different angles the ſlope of earth makes, are of excellent uſe in practice: for it is eaſily perceived, that when the ſoil is of a ſtrong nature, ſuch as loam or clay, a great deal of maſonry may be ſaved, and when the ſoil is ſandy, how to proceed with method and ſafety, which cannot be done without them, or by gueſs only.

PROBLEM V.

To find the thickneſs above, of a ſtone wall which ſupports a parapet of earth above it, according to the fourth profil. Fig. 4.

We ſhall for conveniency ſake, ſuppoſe the ſlope C G of earth to be parallel to D H, that which the earth forms; though this is not always the caſe in practice, yet the difference ariſing from thence is inconſiderable.

Let the vertical line D C produced, meet the horizontal one G H in F; if D C $= a$, D F $= b$, and the reſt as before; then if from the momentum of the triangle D F H, which has been found in Cor. 2. after the firſt problem to be $\frac{4}{17} ssb^3$, we ſubtract the momentum of the triangle C F G, we ſhall have the momentum of the earth.

Now as CF $= b - a$; the preſſure of that triangle will be $\frac{1}{3} \times ss \times \overline{b-a}^2$, by Cor. 1 after the firſt problem; and ſince the diſtance of the line of direction drawn from the center of gravity of this triangle perpendicular to D F, from the point fix A, is D C $+ \frac{2}{3}$ CF, or $\frac{a+2b}{3}$; and the product of this diſtance multiplied by the weight, gives $\overline{b^3 - 3abb + a^3}$ for

Table I
Walls *w*

	When the Slope			
height	*Thickn.ˢ above*		*Thic belo*	
Feet	*Fᵗ*	*In.*	*Fᵗ*	
10	1 :	3	3	:
12	1 :	6	3	:
14	1 :	9	4	:
16	2 :	0	5	:
18	2 :	3	5	:
20	2 :	6	6	:
22	2 :	9	7	:
24	3 :	0	7	:
26	3 :	3	8	:
28	3 :	6	9	:
30	3 :	9	9	:
32	4 :	0	10	:
34	4 :	3	11	:
36	4 :	6	11	:
38	4 :	9	12	:
40	5 :	0	13	:
42	5 :	3	13	:
44	5 :	6	14	:
46	5 :	9	14	:
48	6 :	0	15	:
50	6 :	3	16	:

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height	*Thi al*
Feet	*F.*
10	2
12	2
14	3
16	3
18	3
20	3
22	4
24	4
26	4
28	4
30	5
32	5
34	5
36	5
38	6
40	6
42	6
44	6
46	7
48	7
50	7

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for the momentum of that triangle; which therefore being ſubtracted from $\frac{4}{27}ssb^3$, gives $\frac{2}{27}ss\times\overline{3abb-a^3}$.

Now becauſe the momentums of the wall and counterfort are the ſame here as in the third problem, if we divide the momentum of earth by $\frac{1}{2}a$, and multiply by 3×64, we get $768ss\times\overline{3bb-aa}$ which being ſubſtituted inſtead of the firſt term under the radical ſign in the equation of that problem we get $72x+72na+4.5a=\sqrt{768ss\times\overline{3bb-aa}-60.75aa+1728nnaa}$, for the equation which determines the unknown quantity x in this caſe.

When FC becomes $=0$, that is when there is no parapet of earth above the wall; then will $a=b$, and the laſt equation becomes the ſame as that in the third problem.

If the baſe AE of the ſlope is one fifth of the height EB; and the angle CDH 45 degrees; then will $n=.2$ and $ss=.5$: and the equation above becomes $72x+18.9a=\sqrt{1152bb-375.63aa}$, in this caſe; but if the baſe AE be one ſixth of the height BE, and the angle CDH, the ſame as before, we get $72x+16.5a=\sqrt{1152bb-396.75aa}$.

By means of theſe two laſt equations, the fifth and ſixth tables have been conſtructed, which contain the ratio's between the height of walls and their thickneſs above: they ſhall be explained by a few examples.

Let the height of a ſtone wall be to that of the earth above it as 3 to 2; then becauſe $3:2::a:\frac{2}{3}a=$ CF, we get $a+\frac{2}{3}a=\frac{5}{3}a=b$; whoſe ſquare being multiplied by 1152 gives 3200; from which ſubtracting 375.63, and extracting the ſquare root of the difference, we get 53.144, from which ſubtracting 18.9 and dividing by 72, gives $x=.476a$ nearly, in the firſt caſe.

But if we ſubtract 396.75 from 3200, and extract the ſquare root of the difference, we ſhall have 52.945; from which 16.5 being ſubtracted, and the difference divided by 72, gives $x = .506a$ nearly, in the ſecond caſe.

If the height of the wall is to that of the earth above it, as 4 to 3; then will $b = \frac{7}{4}a$; this value being ſubſtituted into $1152bb$, gives 3528, from which taking 375.63, and extracting the ſquare root of the remainder, we get 56.145; if we take 18.9 from this and divide the remainder by 72, we ſhall have $x = .517a$ nearly, in the firſt caſe.

But if we ſubtract 396.75 from 3528 and extract the ſquare root of the difference, we get 55.975; from this ſubtracting 16.5 and dividing by 72, we ſhall have $x = .548a$ nearly, in the ſecond caſe.

If the walls are built of brick, then by what has been ſaid at the end of the ſecond problem, we have no more to do than to increaſe the firſt term under the radical ſign, in the ratio of 4 to 5; then the general equation above, becomes that for brick walls. Whence, if the baſe A E of the ſlope is one fifth of the height B E, and the angle C D H, is 45 degrees; then will $n = .2$, $ss = .5$; and $72x + 18.9a = \sqrt{1440bb - 471.63aa}$, will be the equation in this caſe: and if that baſe be one ſixth of the height B E, and the angle C D H, the ſame as before, we have $n = \frac{1}{6}$, $ss = .5$: and therefore $72x + 16.5a = \sqrt{1440bb - 492.75aa}$ will be the equation.

Let the height of the wall be to that of the earth above it as 5 to 2; then will $b = \frac{7}{5}a$, whoſe ſquare multiplied by 1440 gives 2822.4, from which ſubtracting 471.63, and the ſquare root being extracted, gives 48.484, and taking 18.9 from this, the remainder divided by 72 gives $x = .411a$, nearly in the firſt caſe.

But if we ſubtract 492.75 from 2822.4 and extract the ſquare root of the difference, we get 48.266 and 16.5 being taken from it; the difference divided by 72 gives $x = .441a$, nearly in the ſecond caſe.

Expla-

Explanation of the following TABLES.

The fifth and ſixth, contain the ratio's between the heights of ſtone walls and their thickneſs above, when there is a parapet of earth above them; the baſe of the ſlope being one fifth and one ſixth of the height of the wall; and the ſlope of earth makes an angle of 45 degrees; the ratio's between the height of the wall to that of the earth above it, are marked in the firſt vertical and horizontal columns: the length of the counterforts being one fourth of the walls height, and their thickneſs is to the interval between them, as unity to 3: that is the ſame as before: The ſeventh and eighth tables contain the ſame ratio's when the walls are of brick.

Their uſes are as follows: when the height of the wall is given, as well as that of the earth above it, reduce the ratio to its loweſt term; look in the firſt vertical column for the antecedent, which is always ſuppoſed to expreſs the height of the wall, and for the conſequent in the firſt horizontal column, then the number oppoſite to the firſt, and under the ſecond, expreſſes the ratio between the height of the wall to its thickneſs above. This number being multiplied by the height of the wall, and the three laſt figures taken as decimals, gives the thickneſs required.

Example, Let the height of a ſtone wall, whoſe ſlope is one fifth, be 20 feet, and that of the earth above it 12: then becauſe 20 is to 12 as 5 is to 3; look in the firſt vertical column of the fifth table for 5, and in the horizontal one for 3: then the number 442 oppoſite to the firſt, and under the ſecond, being multiplied by 20, the height of the wall, gives 8.84 or 8 feet 10 inches nearly for its thickneſs above.

If the height of a ſtone wall, whoſe ſlope is one fifth, be 13 feet, and that of the earth above it 6: then in the ſame table, the number 371 oppoſite to 13 and under 6, multiplied by 13, the height of the wall, gives 4.823 or 4 feet 9 inches nearly for the thickneſs above.

But if the ſlope is one ſixth, look into the ſixth table oppoſite to 13 and under 6, and you will find 403, which being multiplied by 13, gives 5.239 or 5 feet 3 inches nearly. We have not inſerted the thickneſs of the walls near the foundation; becauſe they may be found by adding the baſe of the ſlope to the thickneſs above.

N. B. Thoſe ſquares which are marked with a point only, are oppoſite to ſuch ratio's as have been determined before, and therefore it would have been needleſs to repeat them. Thus the ratio of 2 and 2, of 3 and 3, of 6 and 6, &c. is the ſame as that of unity to unity; and it is the ſame in reſpect to all other equal ratio's.

PROBLEM VI.

To find the thickneſs above BC *of a wall when the counterforts have a ſlope as* F G. Fig. 5.

Draw F L perpendicular to the baſe A G; then if for conveniency ſake, we ſuppoſe C F to be one eighth, and the baſe D G three eighths of the height D C; the area of the rectangle D C, will be $\frac{1}{8}aa$, that of the triangle L G F, will alſo be one eighth of aa; and becauſe the diſtances of the lines drawn through the centers of gravity, of the rectangle D F, and of the triangle F L D, perpendicular to the baſe D G, from the point fix A, are $AD+\frac{1}{2}DL$, $AL+\frac{1}{3}LG$; that is, $x+na+\frac{1}{16}a$; $x+na+\frac{5}{24}a$; and therefore their ſum, multiplied by $\frac{1}{8}aa$, and the product reduced in the ratio of 4 to unity, as has been ſhewn in the third problem, gives $\frac{1}{16}aax+\frac{1}{16}na^3+\frac{325}{384}a^3$, for the momentum of the counterforts, which being added to that of the wall found in the ſecond problem, and the ſum made

Table V. Containing the Proportions between the Height of Stone Walls and that of the Earth above them the Base of the Slope being $\frac{1}{5}$ of ye height

0	1	2	3	4	5	6	7	8	9	10
1	641	1125	1604	2079	2553	3026	3499	3971	4443	4915
2	391	.	885	.	1365	.	1842	.	2316	.
3	305	476	.	804	965	.	1285	1445	.	1762
4	261	.	517	.	763	.	1005	.	1246	.
5	235	340	442	542	.	739	836	933	1029	.
6	217	.	.	.	559	.	723	.	.	.
7	205	280	354	427	498	570	.	711	781	850
8	194	.	327	.	454	.	579	.	702	.
9	186	247	.	363	420	.	532	587	.	695
10	180	.	287	.	.	.	491	.	591	.
11	173	225	273	321	368	414	460	506	551	596
12	171	.	.	.	349	.	433	.	.	.
13	168	211	251	292	332	371	411	449	488	527
14	165	.	242	.	318	.	391	.	463	.
15	162	199	.	270	.	.	374	408	.	.
16	160	.	228	.	294	.	359	.	423	.
17	158	190	222	254	285	316	346	376	406	436
18	156	.	.	.	276	.	334	.	.	.
19	154	183	212	240	268	296	323	351	377	405
20	152		208	.	.	.	314	.	366	.

pag 2

Table VI. Containing the Proportions between the Height of Stone Walls, and that of the Earth above them, the Base of the Slope being $\frac{1}{6}$ of the height

0	1	2	3	4	5	6	7	8	9	10
1	672	1157	1636	2112	2586	3060	3532	4004	4477	4949
2	422	.	917	.	1397	.	1874	.	2349	.
3	335	506	.	835	997	.	1317	1477	.	1796
4	291	. .	548	.	796	.	1037	.	1277	.
5	264	370	472	574	.	770	868	965	1061	.
6	246	.	.	.	589	.	756	.	.	.
7	233	310	384	458	530	604	.	742	812	882
8	223	.	357	.	485	.	610	.	734	. .
9	216	276	.	393	450	.	562	617	.	726
10	209	.	317	.	.	.	523	.	625	.
11	204	254	302	350	400	444	497	536	582	627
12	200	.	.	.	379	.	464	.	.	--
13	196	239	281	322	362	403	441	480	519	557
14	193	.	272	.	347	.	421	.	494	.
15	191	228	.	300	.	.	404	439	.	.
16	188	.	257	.	324	.	388	.	453.	.
17	186	219	233	284	316	346	377	408	438	466
18	184	.	.	.	307	.	364	.	.	.
19	183	213	241	270	299	327	354	382	409	435
20	181	.	237	.	.	.	344	.	400	.

Table VII. Containing *the* Proportions *between the* Height *of Brick* Walls *and that of the* Earth *above them the Base of the Slope being* [illegible] *of the height*

0	1	2	3	4	5	6	7	8	9	10
1	748	1289	1824	2355	2885	3414	3943	4471	4999	5527
2	468	.	1020	.	1557	.	2089	.	2620	.
3	372	562	.	929	1110	.	1468	1646	.	2001
4	323	.	609	.	884	.	1155	.	1424	.
5	293	411	523	637	.	857	966	1074	1182	.
6	273	.	.	.	655	.	838	.	.	.
7	259	344	427	509	589	668	.	826	904	974
8	248	.	396	.	639	.	678	.	816	.
9	239	306	.	436	500	..	624	686	.	808
10	232	.	352	.	.	.	581	.	692	.
11	227	282	336	390	442	494	545	596	647	697
12	222	.	.	.	420	.	516	.	.	.
13	218	266	312	357	402	446	490	533	576	619
14	215	.	302	.	386	.	468	.	549	.
15	212	253	.	333	.	.	449	487	.	.
16	209	.	286	.	360	.	432	.	594	.
17	207	243	279	314	349	383	418	452	485	518
18	205	.	.	.	340	.	404	.	.	.
19	203	236	268	300	331	362	392	423	453	843
20	201	.	263	.	.	..	382	.	440	.

Table VIII. Containing *the* Proportions *between the* Height *of Brick* Walls *and that of the* Earth *above them the Base of the Slope being* ⅛ *of the height*

0	1	2	3	4	5	6	7	8	9	10
1	779	1322	1856	2388	2918	3447	3976	4504	5032	5559
2	499	·	1052	·	1589	·	2122	·	2653	·
3	402	593	·	961	1142	·	1500	1678	·	2034
4	354	·	640	·	916	·	1187	·	1456	·
5	323	441	556	668	·	888	997	1106	1214	·
6	320	·	·	·	687	·	870	·	·	·
7	288	374	459	539	620	700	·	858	935	1013
8	277	·	427	·	570	·	710	·	848	·
9	269	336	·	467	530	·	656	717	·	840
10	262	·	383	·	·	·	612	·	724	·
11	256	312	367	420	473	525	576	627	678	729
12	251	·	·	·	451	·	546	·	·	·
13	247	295	341	387	432	477	521	564	608	651
14	244	·	332	·	416	·	·	·	580	·
15	241	282	·	362	·	·	480	518	·	·
16	238	·	315	·	390	·	463	·	535	·
17	236	273	309	344	379	414	448	482	516	548
18	234	·	·	·	369	·	435	·	·	·
19	232	265	298	329	361	392	423	453	484	512
20	230	·	293	·	·	·	412	·	470	·

made equal to that of the earth; after having multiplied by $\frac{1}{2}a$, and the ſecond ſide reduced under the ſame denomination, and the root of the firſt multiplied by the root of the common denominator 81×64, we get $72x + 72na + 4.5a = a\sqrt{1536ss - 67.5 + 1728nn}$, for the equation required, which differs from that found in the third problem, by the term 67.5, which there is 60.75.

Hence, if $n = .2$, and $ss = .5$; theſe values multiplied by their coefficients, gives 769.62, for the ſum of the terms under the radical ſign, whoſe ſquare root is 27.742, from which ſubtracting the ſum 18.9 of the two known terms, and the difference divided by 72, gives $x = .1228a$, which is leſs than that found in the third problem; but not ſo much as is worth taking notice of: ſince in a wall of 30 feet high, the difference is only .7 of an inch: conſequently either of theſe counterforts may be uſed according to the builders fancy.

Sometimes counterforts may be made with ſteps, which may be done by making them ſo as that the baſe and the area be the ſame, without changing its momentum.

Fig. 6. Sometimes the ſection of walls are made parallelograms without any counterforts, eſpecially when they are low: ſuch as ABCD: To find their thickneſs AD or BC; draw the diagonal AC, and through the middle L, and the point C, the lines LK, CE perpendicular to the baſe AD produced; and let $AD = x$, $DE = na$, and $CE = a$; then will ax expreſs the area of the parallelogram DB; and ſince the point L is the center of gravity of the parallelogram, AK will be the diſtance of the line of direction from the point A; but becauſe AL is half of AC, the diſtance AK, will be $\frac{1}{2}x + \frac{1}{2}na$, half the diſtance AE. Therefore the area ax multiplied by the diſtance AK, gives $\frac{1}{2}axx + \frac{1}{2}aanx$, for its momentum, and ſo equal to $\frac{4}{27}ssa^3$ that of the earth by the firſt problem;

which being divided by $\frac{1}{2}a$, and $\frac{1}{4}nnaa$, added to both ſides: the firſt will be a perfect ſquare whoſe root is $18x + 9na = a\sqrt{96ss + 81nn}$, after having reduced the ſecond ſide under the ſame denomination, and multiplied the root of the firſt by the root of the denominator 324, of the ſecond.

If the firſt term $96ss$ under the radical ſign be increaſed in the ratio of 4 to 5, we ſhall have $18x + 9na = a\sqrt{120ss + 81nn}$ in walls built with bricks.

Hence if $n = .2$, and $ss = .5$; we ſhall get $x = .31a$ nearly in ſtone walls, and $x = .355a$, in brick walls.

Hence it may be eaſily known whether theſe kinds of walls require more maſonry, than thoſe in the firſt figure without counterforts: for we have found in the ſecond problem, when n and ss, expreſſed the ſame values as here, that $x = .2018a$, and therefore the area of that profil, will come out to be $.3018aa$; and the area of the parallelogram DB, is $.31aa$: therefore the difference $.0082aa$, ſhews that this laſt figure requires more than the former; tho' not much in low walls.

Before we conclude this ſection, we ſhall add one general problem more, in order to ſhew that it would have been eaſy to reduce almoſt every thing into a few problems, were it not neceſſary to menage the learners capacity, and to lead him gradually from the moſt ſimple and eaſy truths, to others more complex.

PROBLEM VII.

Let the profil of a ſtone wall be a parallelogram as DB, *and the counterforts a trapezium* DCFH, *whoſe outward ſlope* FH *being equal to* CD *that of the wall, to find the thickneſs of the wall when there is a parapet of earth above it.* Fig. 7.

If for conveniency ſake, CF be one tenth of the height CE; and the reſt being the ſame as before;

then will DH $= 2na + \frac{1}{10}a$; which being added to CF, $\frac{1}{10}a$, and the ſum multiplied by half the height CE, gives $naa + \frac{1}{10}aa$ for the area of the trapezium, which being multiplied by AD $+ \frac{1}{2}$ DH, that is $x + na + \frac{1}{20}a$, and the product reduced in the ratio of 4 to unity, gives $\frac{1}{40}aax + \frac{1}{4}nna^3 + \frac{3}{80}na^3 + \frac{1}{800}a^3$ for its momentum; which being added to $\frac{1}{2}axx + \frac{1}{2}naax$ that of the wall found above, and the ſum made equal to $\frac{2}{27}ss \times \overline{3abb - a^3}$ that of earth, found in the fifth problem; the whole being divided by $\frac{1}{2}a$, and $\frac{1}{16}nnaa - \frac{3}{80}naa - \frac{1.5}{800}aa$, added to both ſides, the firſt will be a perfect ſquare, and the ſecond, being reduced under the ſame denomination, gives $36x + 27na + .9a = \sqrt{192ss \times \overline{3bb - aa} + 81nnaa - 48.6naa - 2.43aa}$, after having multiplied the firſt ſide by 36 the root of the common denominator 1296 of the ſecond.

When the wall is made of brick, there need no more than to increaſe the coefficient 192, of the firſt term under the radical ſign, in the ratio of 4 to 5, which gives 240 for that coefficient in this caſe; the other terms will remain the ſame as before.

When there is no parapet of earth above the wall, then will $b = a$; and the firſt term under the radical ſign becomes $384ssaa$, and the reſt will remain as before.

When $n = .2$, and $ss = .5$; then will $36x + 6.3a = \sqrt{288bb - 104.91aa}$, in ſtone walls: but if $n = \frac{1}{6}$, and $ss = .5$; then will $36x + 5.4a = \sqrt{288bb - 98.97aa}$.

And if $b = a$; that is, if there is no parapet of earth above the wall, we ſhall have $x = .202a$, in the firſt caſe, and $x = .232a$, in the ſecond. But if the height of the wall is to that of the earth above it, as 4 to 3, then will $b = \frac{7}{4}a$; the ſquare of which being ſubſtituted into the two equations, gives $882aa$, for the firſt term under the radical ſign, and the ſquare root being extracted, we ſhall find that $x = .6a$ nearly in the firſt caſe, and $x = .627a$, in the ſecond.

Hence it is very eaſy to compare the quantity of maſonry, contained in walls, whoſe profil is a parallelogram as in this figure, and the counterforts a trapezium; and thoſe whoſe profil is a trapezium, and the counterforts rectangles, as in the ſecond profil: for the area of the profil in the ſecond figure, with that of the counterfort reduced, is found to be $.287aa$, when $n = \frac{1}{5}$, and $.299aa$, when $n = \frac{1}{6}$.

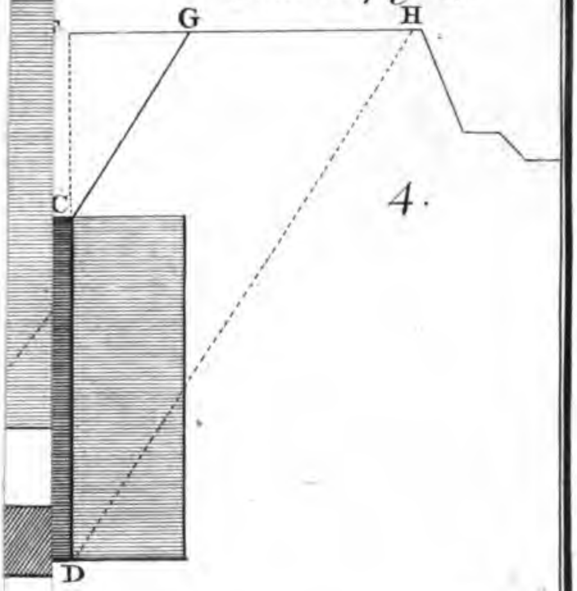
And the area of the profil and counterfort according to the ſeventh figure, is found to be $.277aa$ when $n = \frac{1}{5}$; and $.298aa$, when $n = \frac{1}{6}$.

Therefore the profil in the form of a parallelogram, requires leſs maſonry than that whoſe figure is a trapezium; and the difference is greater when $n = \frac{1}{5}$, than when $n = \frac{1}{6}$; but when n is one ſeventh or eighth, the trapezium figure has the advantage, as will be found by computation.

Thus we have ſhewn how to find the thickneſs of walls, ſuch as ſhall reſiſt the preſſure of the earth, of all the different profils, that may be uſed; and it will eaſily appear, that our method is both more general, and much eaſier than that given by other authors; the many general rules given here before, and their eaſy application to practice, are convincing proofs of it; beſides no author has attempted before to give tables for ramparts with demi-revetements; though they are much more uſeful than any others, on account, that the moſt experienced engineers, ſcarcely build any others now-a-day, and that for very good reaſons; becauſe it ſaves great expences, beſides they are not ſo eaſily deſtroyed by battering pieces, and when a breach is made, are ſoon repaired.

It may perhaps be ſaid, that we have reduced the counterforts to certain figures which are eaſily computed, and therefore our ſolutions are not ſo general as is pretended: But if the reader be pleaſed to conſi-

Plate I. page 26



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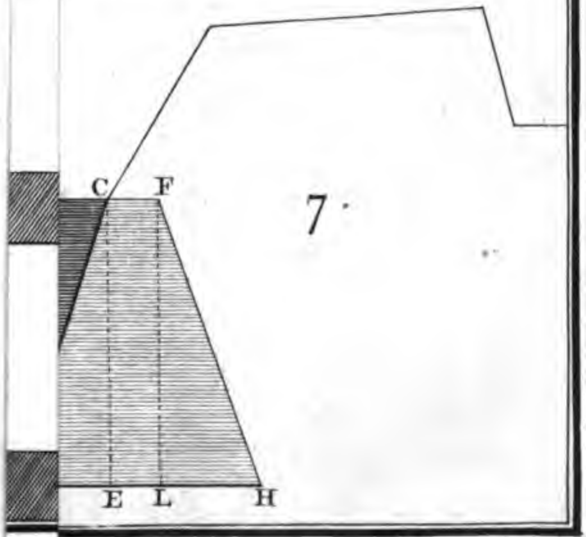

7.

J. Couse Sculp^t

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der that the length given here agrees very nearly with that given by Mr. *Vauban*, and the rectangular form has been ſhewn to be more advantageous, than that of a trapezium, beſides it is generally uſed here; as to thoſe whoſe profil is a trapezium, ſuch as in the fifth and ſixth figure; regard has been had to ſuch dimenſions as are moſt uſeful in practice, and ſuch as are of a due proportion in reſpect to the walls which they are to ſtrengthen.

SECT. II.

The THEORY *of* ARCHES.

IN fortreſſes it is abſolutely neceſſary to build vaults and arches, ſuch as over gate-ways, under-ground paſſages, from the body of the place to the ditch, powder-magazines, cazemats, and lodgings for the ſick and wounded, and for thoſe which are not on duty, to reſt in with ſafety

It is of no little importance, in the building of a fortreſs, to know exactly, and with certainty, what thickneſs piers that ſupport arches of various magnitudes, require in different circumſtances, ſo as to make the work durable, and to uſe no more materials than it requires. The making powder-magazines, ſo as to reſiſt the ſhells thrown upon them in a ſiege, requires the utmoſt ſkill of an engineer, and has not hitherto been rightly determined by any body I know of. The engineers generally follow the dimenſions of thoſe conſtructed by Mr. *Vauban*, which indeed have ſo well ſucceeded, that it ſeems to be unneceſſary to attempt any other rules to go by; were it not required, in many caſes, to make arches of different width, figure, higher and lower; and therefore, it will be proper to lay down general rules, which ſhall anſwer all theſe various circumſtances.

It is one of the moſt difficult problems in mechanics, to find the momentum or force with which different kinds of arches act againſt the piers that ſupport them; and though many great mathematicians have endeavoured to ſolve it, eſpecially the gentlemen of the royal Academy of Sciences at *Paris*, and Mr. *Belidor* in his book called *La ſcience des Ingenieurs*; yet, if I am not miſtaken, neither of them has ſucceeded; for whoever reads their performances will be more convinced of the difficulties that attend it, than of the truth of their ſolutions; and it is eaſily perceived that ſome of them are miſtaken, and have perplexed themſelves with tedious algebraic expreſſions, which when applied to eaſy practical caſes are impoſſible, which ſhews that their computations are built upon erroneous principles.

It is true, Mr. *Belidor* has better ſucceeded in his principles than many others; yet his applications are not free from objections, as will appear hereafter, and which is the reaſon that the thickneſs of the piers he aſſigns are ſo much leſs than they ſhould be.

It ſeems to be a difficult matter to determine this problem exactly, on account of the ſuppoſitions which are neceſſarily to be made in regard to the cement that is uſed in the joints, in order to keep the arch-ſtones together.

Thoſe who go upon the refined ſuppoſition that the joints are quite ſmooth and poliſhed, without any mortar, are greatly miſtaken; for beſides that no ſuch thing ſubſiſts in practice, their ſolutions when applied to practical examples, give nothing but impoſſibilities, as any one may be convinced who reads them with attention.

In the enſuing work, we ſhall ſuppoſe with Mr. *Belidor*, that the arch-ſtones are laid in mortar, and ſo cemented together as to prevent their ſliding upon one another; but not ſo hard as to compoſe as it were one ſolid ſtone, becauſe this would be a plain contradiction, ſince it could not act upon the piers in an oblique manner; out the mortar being of ſuch a conſiſtence only, that if the piers were not ſufficiently ſtrong, the arch would break in the weakeſt part, and thereby overturn the piers. This ſuppoſition is the moſt natural that can be made, and has been found true in practice; for ſeveral arches have fallen down, for want of ſufficient ſtrength in the piers to reſiſt their preſſure; beſides mortar requires ſome time to harden, which being once effected, no accidents happen afterwards.

PROBLEM I.

To find the preſſure of an arch againſt the piers that ſupport it. Plate II. Fig 1.

Let A E F G be the ſection of half the arch, ABCD that of the pier which ſupports it; the point C taken near the foundation, may be conſidered as fixed, and about which the pier muſt turn to be overſet; M N, one of the arch-ſtones; O the center where all the joints meet when produced; and laſtly, let A S be the line which terminates the ſpring of the arch.

From the center of gravity X of the ſtone M N, draw a line X Q perpendicular to the under joint O M, meeting C D produced if neceſſary in R, and let C Q be perpendicular to that line; and X T to the horizontal line A O; laſtly, from any point L in O M, draw L K perpendicular to A O.

From a known principle in mechanics, three powers are in equilibrio, or in a ſtate of reſt, when they are to each other as the ſides of a triangle which are perpendicular to their directions: Now ſince K O is perpendicular to the direction X T, of the gravity, O L to the direction X Q in which the gravity of the ſtone acts againſt the joint O M, and L K to that in which it acts in an horizontal direction againſt the oppoſite part of the arch; and as this laſt action is deſtroyed by an equal force of the ſtone *x* equally diſtant from the middle O F in an oppoſite direction; there remains the force only expreſſed by O L, which acts againſt the joint O M, to be conſidered.

But becauſe this force produces more or leſs effect according as its direction X Q is farther from, or nearer to the point fix C; it is evident that the effect of this force is in the compound ratio of the force L O and the diſtance C Q of its direction from the point fix C. But becauſe of the right angled ſimilar triangles O K L, C Q R, we have $CQ : CR :: KO : LO$; or $CQ \times LO = CR \times KO$; conſequently, the momentum of this force is alſo in the compound ratio of the gravity K O of the ſtone N M, and the reſpective diſtance C R, between the point fix C, and the interſection of the direction X Q, with the vertical line C V.

Whatever has been ſaid with regard to the ſtone MN, is equally true with regard to any other whatſoever; and therefore the ſum of all the products of the weights of the ſtones contained in half A F the arch, each multiplied by its reſpective diſtance C R, will expreſs the total momentum or effect of the preſſure againſt the pier A C: becauſe the preſſure of the other half arch acts againſt the oppoſite pier.

By a known property of the center of gravity, the ſum of the momentums of all the parts, is equal to the whole weight applied to the center of gravity. Whence if L be the center of gravity of half A F the arch and L H be drawn perpendicular to the joint that paſſes through that center meeting C D in I; the weight of half the arch A F, multiplied by the diſtance C I, will expreſs the momentum of the preſſure againſt the pier A C.

COR.

Hence if the weight W, ſuſpended in the middle of the baſe B C of the pier, be ſuppoſed to expreſs the area A B C D; and *n* the area A E F G, of half the arch, then will $\frac{1}{2} BC \times W$ expreſs the momentum of the pier, and $CI \times n$ that of the arch's preſſure; therefore we have $BC \times W = 2n \times CI$, in caſe of equilibrio.

REMARK I.

As the ſurfaces of the arch-ſtones are generally very rough, and beſides the mortar renders them leſs liable to ſlide upon one another, than they would do without it; the momentum we have here given is more than what ariſes barely from the weights of the arch-ſtones: and we have ſhewn in the theory of walls, that a body placed on a ſmooth horizontal plane, requires one third of its weight to be moved; it is evident that the momentum of the arch might be diminiſhed by one third; but as arches under ground ſupport a weight of earth, beſides its own, and thoſe above ground, ought to reſiſt the force of ſhells, we ſhall not diminiſh that momentum hereafter in our computation; leaving to the engineers to make it leſs whenever they ſhall think it neceſſary; which they may do, by ſuppoſing n to expreſs either the two thirds or one half of the area $AEFG$; in the following equations.

REMARK II.

As the angle AOL increaſes, ſo the perpendicular QC or the momentum of the arch increaſes, till that angle becomes a right one; then CQ becomes equal to the line CV, terminated by the horizontal line, paſſing through the middle of the upper joint EF; and therefore CV is the greateſt diſtance CQ of all; and when XQ paſſes through the point fix C; then CQ becomes nothing; and when the direction XQ paſſes between the points B, C, it becomes negative, and the greateſt when equal to $DG + \frac{1}{2} AG$, and the part of the arch from the point where $CQ = 0$ to the ſpring AD, inſtead of acting againſt the pier, add ſtrength to it, but as the above property of the center of gravity is general, whether a part is negative or not; we have no occaſion to conſider the negative part ſeparately.

REMARK III.

There is a remarkable property of the center of gravity, which being very uſeful in what follows, we ſhall mention here, *viz.* *The ſolid content deſcribed by any plane ſurface, either in moving parallel to itſelf, or about a line as an axis; is always equal to the product of the generating plane, and the line deſcribed by its center of gravity.* This property has been demonſtrated in our treatiſe of Conic ſections, page 147, as likewiſe in our Elements of math. page 253, 254, 255.

PROBLEM II.

To find the thickneſs B C *of the piers when the arch is terminated by two concentric circles deſcribed from the center* O *placed in the line* A S, *which paſſes through the ſpring of the arch.*

Let the radius O A of the interior circle be called a, and of the exterior one $OG = b$, the height A B of the piers c, its thickneſs B C ſought z: then if unity is to r, as the radius to the ſemi-circumference; we have ra, rb, for the ſemi-circumferences of the radii O A and O G; therefore $\frac{1}{4}raa$, $\frac{1}{4}rbb$, expreſs the areas of the quadrants, whoſe difference is equal to n, by the laſt cor. that is, $4n = rbb - raa$: Now ſince the ſemi-ſpheres deſcribed by theſe quadrants about the axis, O A or O E, are the two thirds of the cylinders of the ſame baſe and altitude, and becauſe raa, rbb, are the baſes, and a, b, the altitudes, we ſhall have $\frac{2}{3}ra^3$, $\frac{2}{3}rb^3$, for the ſolid contents of the ſemi-ſpheres; and their difference will by the laſt remark, be equal to the product of the area $AF = n$, multiplied by the circumference deſcribed by the center of gravity L;

but $2r$ is to unity as KL is to $2r$ KL the circumference deſcribed by the radius OK or KL: Therefore $3n$ KL $= b^3 - a^3$, by the third remark after having multiplied by 3, and divided by $2r$.

Now if we call OK or KL $= m$; then becauſe the radius OM which biſects the arcs AE, GF, biſects alſo the quadrants, and therefore paſſes through the center of gravity, and the right angled triangles OKL, OLH, HDI, are iſoſceles; that is, OH $= 2m$, DH $=$ DI $= a + z - 2m$, and CI $= c + 2m - a - z$: or if $g = c + 2m - a$; then will CI $= g - z$; which being multiplied by $2n$ according to the Cor. after Prob. I. the product muſt be equal to the product czz, of the area cz of the pier, by z; therefore $czz = 2ng - 2nz$, or $czz + 2nz = 2ng$; but if we multiply both ſides by c, and add nn, the firſt ſide will be a perfect ſquare, whoſe root is $cz + n = \sqrt{2cng + nn}$.

It may be obſerved, that if the equality $3n$ KL $= b^3 - a^3$, be divided by the equality $4n = rbb - raa$, we ſhall have $\frac{3r}{4} \times \mathrm{KL} = a + \frac{bb}{a+b}$, after having multiplied by r; from whence the value of KL $= m$, is eaſily found.

Example, Let $a = 12$, $b = c = 15$: then becauſe $r = 3.14159$, we ſhall have $n = \frac{1}{4} r \times \overline{bb - aa} = 63.617$: $\frac{3r}{4} m = a + \frac{bb}{a+b} = 20\frac{1}{3}$; and hence $m = 8.629$, and $g = c + 2m - a = 20.258$; and if we take the two thirds of 63.617, the area for the value of n, on account of the friction, as we did in reſpect to the earth in the former ſection, we ſhall have 42.411 for the value of n: Hence $2cg + n = 650.151$, which multiplied by (n) 42.411, gives 27573.554, for the ſum of the terms under the radical ſign, whoſe root is 166.053; from which ſubtracting the known term (n) 42.411, and dividing by the coefficient (c) 15, we get $z = 8.243$, nearly, or BC of 8 feet 3 inches nearly.

But if we take half the value of 63.617 the area for n; then will $n = 31.808$, and $2\,cg + n = 639.548$, which multiplied by 31.808 gives 20342.742784 for the ſum of the terms under the radical ſign, whoſe ſquare root is 142.628; from which ſubtracting 31.808 the known term, and the difference divided by the coefficient (c) 15 gives $z = 7.354$, or B C of 7 feet 4 inches nearly.

And if we take the whole area A F for the value of n, we ſhall find by the ſame operation as before, that B C is 9 feet 6 inches nearly.

Mr. *Belidor* found this thickneſs 6 feet 6 inches only; the reaſon is, that he takes but half the area A F for the value of n, and adds the other half to the pier; and as this would reduce the thickneſs of the piers, to a trifle, he draws the line L I, of direction through the middle of the joint at M, which makes the diſtance C I, greater than it ſhould be, whereby his value is increaſed, though not as much as it ought to be; as appears by the examples above.

It will be proper to obſerve, that if the piers are built with large ſtrong ſtones, and the arch bears no other weight than its own; one half of the area A F will be ſufficient for the value of n; but if the piers are not very ſolid, two thirds of that area muſt be taken for the value of n, and the whole in powder magazines, where the piers ought not only to be capable to ſupport the arch, but likewiſe the ſhock of the ſhells thrown upon it in time of a ſiege.

PROBLEM III.

To find the thickneſs B C *of the piers when the outſide* G F *is a right line perpendicular to the radius* O M *which biſects the quadrant* O A E. Fig. 2.

It is evident that the triangles O L H, H D I, are the ſame here as in the firſt figure, and therefore this problem differs from the former only in the values of n and m, whence if $OM = b$, and the reſt as before; then becauſe the right angled triangle G O F is iſoſceles, we have $GF = 2b$, and ſo bb expreſſes the area of that triangle, and as $\frac{1}{4} raa$ expreſſes the quadrant O A E, we have $n = bb - \frac{1}{4} raa$.

Becauſe $OF = b\sqrt{2}$, the cone deſcribed by the triangle O F G, about the axis O F, will be expreſſed by $\frac{2}{3} r b^3 \sqrt{2}$, and the ſemi-ſphere being $\frac{2}{3} r a^3$, by the laſt problem; and ſince unity is to $2r$, as the radius KL or OK (m) is to the circumference $2rm$ deſcribed by the center of gravity L in the rotation, we have $3nm = b^3\sqrt{2} - a^3$, by remark the third, after multiplying by 3 and dividing by $2r$: conſequently $g = c + 2m - a$, and $cz + n = \sqrt{2cgn + nn}$ as before.

REMARK.

It is to be obſerved, that the thickneſs of the arch in the weakeſt part at M, is 3 feet when the opening A S is 24 feet, being nearly the ſame as that given by Mr. *Vauban*, and to find the thickneſs in that place of any other opening, ſo as to make the arch equally ſtrong, the ſpace A G F E, muſt be to the quadrant O A E in the ſame ratio as in this caſe, which will happen when the length of the joint in that place is always one fourth part of the radius of the quadrant; for the triangle O G F, when O M is 15, will be to that triangle when $OM = b$, as 225 to bb, and the quadrant O A E, when O A is 12, will be to that quadrant when O A is a, as 144 to aa; and therefore if $144 : 225 :: aa : bb$; the areas A G F E, will be ſimilar to the quadrants O A E; but when ſquares are proportional, their ſides are ſo; whence $12 : 15 :: a : b$, or $b = \frac{5}{4} a$. Conſequently, this value of b, being ſubſtituted into the values of n and m; 1.4142 for $\sqrt{2}$ and 3.14159, for r, we get $n = .777\,aa$, and $m = .756a$; nearly for theſe values; which therefore are known when the radius a is known.

EXAMPLE.

Let $a = 12$, $c = 15$; then will $n = 112$ nearly, and $m = 9.07$; hence will $g = 21.14$, and if we take $74\frac{2}{3}$ the two thirds of the area AGFE for the value of n, then will $2cg + n = 708.866$, which multiplied by $74\frac{2}{3}$, gives 52928.66 for the ſum of the terms under the radical ſign, whoſe root is 230.062, from which ſubtracting the known term (n) 74.666, and dividing the difference by the coefficient (c) 15, gives $z = 10.359$ or BC equal to 10 feet 4 inches nearly.

If $c = 9$ and the reſt as before, we ſhall have $z = 9.595$, but if we take 56 half the area AGFE, for the value of n; we get $2cg + n = 692.2$, and 38763.2 good the ſum of the terms under the radical ſign, whoſe ſquare root is 196.883, from which ſubtracting 56 the known term, and dividing by the coefficient 15, we get $z = 9.392$, or BC equal to 9 feet 5 inches nearly: whereas Mr. *Belidor* has only found 7 feet 8 inches for the ſame thickneſs, though we have here taken the leaſt value of n that can be.

PROBLEM IV.

To find the thickneſs BC *of the piers when the inſide is a right line parallel to the outſide.*

The ſame thing being ſuppoſed as in the laſt, we ſhall have $n = bb - aa = \frac{9}{16}aa$, and $3mn = \overline{b^3 - a^3} \times \sqrt{2}$ gives $m = .7987a$. As the reſt is the ſame as before, we have $g = c + 2m - a$, and $cz + n = \sqrt{2cgn + nn}$.

EX-

EXAMPLE.

If $a = 12$, $c = 15$; then will $n = 81$, $m = 9.584$, $g = 22.168$; hence $2cg + n = 719.04$, by taking 54 the two thirds of the area 81, for the value of n; and 38828.16 for the ſum of the terms under the ſign, whoſe ſquare root is 197.048; from which ſubtracting the known term 54, and dividing the difference by 15, gives $z = 9.536$ feet for the value required, which is leſs than that we found above: the reaſon is, that the former area has been found to be 112 feet, and here it is only 81. Therefore the piers have here leſs weight ſupport them there.

PROBLEM V.

To find the thickneſs B C *of the piers when the arch is terminated by two circular arcs, deſcribed from the ſame center* O, *below the line* A S *which paſſes through the ſpring of the arch,* Fig. 3.

Let the chord A E be drawn; the radius A O produced ſo as to meet the arc G F in R, and the line O D parallel to P A, meeting C I in D and interſecting the direction L I in H; then if $OA = a$, $OM = b$, $AP = p$, $PE = d$, $AE = b$, and the arc $AE = v$.

This being ſuppoſed, we ſhall have $\frac{1}{2}av$ for the area of the ſector O A E, and as the ſectors O A E, O R F, are ſimilar, they are as the ſquares of the radii; therefore $aa : bb :: \frac{1}{2}av : \frac{bbv}{2a}$ = to the ſector O R E; and $2an = v \times \overline{bb - aa}$, or becauſe $4b = 5a$ by what has been ſaid before, we get $32n = 9av$.

Now becauſe the ſolids deſcribed by theſe ſectors in the rotation of the figure about a line paſſing through the

the center O perpendicular to the radius O M, are the two thirds of the cylinders of the ſame baſes, and whoſe altitudes are the chords of theſe arcs, by art. 217. of our Elem. Math. the baſes being raa, rbb, and the altitudes, b, $\frac{bb}{a}$, theſe ſolids are $\frac{2}{3}raab$, $\frac{2r}{3a}bb'$, and if O L $= m$, then will $3amn = b \times \overline{b\cdot - a'}$ or $54v$ $m = 61ab$.

The right angled triangles O L H, H D I, are ſimilar to the triangle A P E, and therefore P E (d) : A E (b) : : O L (m) : O H $= \frac{bm}{d}$, and ſo D H $= p + z - \frac{bm}{d}$; we have likewiſe A P (p) : P E (d) : : D H : D I $= d + \frac{dz}{p} - \frac{bm}{p}$; now becauſe O P $= a - d$, by ſubtracting the ſum of D I and O P, from the height of the piers c; we ſhall have C I $= c - a + \frac{bm}{p} - \frac{dz}{p}$; or if $g = c - a + \frac{bm}{p}$, it will be C I $= g - \frac{dz}{p}$, and conſequently, $czz = 2ng - \frac{2ndz}{p}$, by cor. after prob. I. and if $dn = pq$; the ſquare root of this equation will be $cz + q = \sqrt{2cng + qq}$.

Hence if the height P E of the arch be the three fourth of half the breadth, A P; that is, if $d = \frac{3}{4}p$; the right angled triangle A P E, gives $b = \frac{5}{4}p$, and the right angled triangle A P O, $25p = 24a$; theſe values being ſubſtituted into thoſe of g, q, and O P $= a - d$; we get $g = c - a + \frac{5}{4}m$, $q = \frac{3}{4}n$, and O P $= \frac{7}{25}a$; but A O (a) is to O P ($\frac{7}{25}a$) as the radius 100000 is to the 28000 coſine of the angle A O E, and therefore this angle is found to be 73 degrees and 45 minutes or $73\frac{3}{4}$ degrees. Now becauſe ra expreſſes the ſemi-circumference of the radius a; and 180 degrees is to $73\frac{3}{4}$ degrees, as the ſemi-circumference ra is to the arc $v = \frac{59}{141} a r$; this value being ſubſtituted into thoſe of n and m found above, as well as 3.14159, that of r gives $n = .362\, a a$, and $m = .8776\, b$.

EXAMPLE.

Let $p = 12$; then will $a = 12.5$, $b = 15$; and if $c = 15$, then will $n = 56.56$, $m = 13.164$, $g = 18.955$; and if we take the two thirds of the area 56.56 for the value of n, we get $q = 28.28$; and therefore 22241.6544 will be the ſum of the two terms under the radical ſign, whoſe root is 149.13, from which the known term 28.28 being ſubtracted, and the difference divided by 15, the coefficient gives $z = 8$ or B C equal to 8 feet nearly, which is 3 inches leſs than when the arch is a ſemi-circle.

PROBLEM VI.

To find the thickneſs B C *of the piers when the outſide* G F *is a right line parallel to the chord* A E, *and the reſt being the ſame as before.* Fig. 4.

It is evident that this problem differs from the former, in the values of m and n only. Whence becauſe of the right angled ſimilar triangles A P E, O M F, we have A P (p) : P E (d) : : O M (b) : M F $= \frac{b d}{p}$; and as M R is equal to M F, we have $\frac{b b d}{p}$ for the area of the triangle O R F, and ſince $\frac{1}{2}\, a v$ expreſſes the area of the ſector O A E by the laſt problem, we have $2 p n = 2 d b b - a p v$.

Now becauſe the ſolid deſcribed by the triangle O R F about an axis paſſing through the center O parallel to the chord A E, is the two thirds of the cylinder of the ſame baſe and altitude; the baſe being

rbb, and the altitude RF, $\frac{2bd}{p}$, this ſolid will be $\frac{4r}{3p}db^3$; and as the ſolid deſcribed by the ſector O A E, in that rotation, is $\frac{2}{3}raab$; we get $3mnp = 2db^3 - aabp$; after having multiplied both ſides by $3p$ and divided by $2r$.

Therefore $g = c - a + \frac{bm}{p}$ and $cz + q = \sqrt{2cng + qq}$, by the laſt: ſuppoſing $dn = pq$. If the center O be ſuppoſed to coincide with the point P; then a, p, and d, are equal, and the equations in the two laſt problems, will then become the very ſame as thoſe in problems the ſecond and third, with this reſerve, that O L is here called m, and L K in the firſt and ſecond figure.

If P E is again the three fourths of A P, we ſhall find the ſame values, as in the laſt; that is, if $\frac{3}{4}p = d$; then will $b = \frac{5}{4}p$, $p = \frac{24}{25}a$, $g = c - a + \frac{5}{4}m$; $v = \frac{59}{144}ar$; and therefore $n = .528\,aa$, $m = 1.092\,a$.

EXAMPLE.

Let $p = 12$, and $c = 15$; then will $a = 12.5$, $n = 82.5$, $m = 13.65$, and $g = 19.56$: and if we take the two thirds of 82.5 the area for the value of n; we get $q = 41.25$, and 33974.5625, for the ſum of the terms under the radical ſign, whoſe ſquare root is 184.32 from which ſubtracting the known term 41.25 and dividing the difference by 15, gives $z = 9.53$ feet; which is about 10 inches leſs than what we have found in the third problem.

N. B. We have neglected the ſmall ſpace A G R, in the two laſt figures, as being but inconſiderable, and would have rendered the operations very tedious; beſides in practice a geometrical exactneſs is impoſſible and not neceſſary; eſpecially when the departing from it, renders the operations more eaſy and ſimple, as it happens here in this caſe.

PROBLEM VII.

To find the thickneſs B C *of the piers, when the arch is terminated by two circular arcs deſcribed from the center* O, *placed in the line* A S, *which paſſes through the ſpring of the arch.* Fig. 5.

It is evident that the values of m and n are here the ſame as in the fifth problem, ſince we have the ſame ſectors and triangles here as in the third figure; therefore $32\,n = 9\,a\,v$ and $54\,v\,m = 61\,a\,b$.

Now becauſe of the ſimilar triangles P E A, O L H, we have P E (d) : A E (b) : : O L (m) : O H $= \frac{bm}{d}$, and ſo $a + z - \frac{bm}{d} =$ D H; and the ſimilar triangles A P E, D H I, give A P (p) : P E (d) : : D H : D I $= \frac{da}{p} + \frac{dz}{p} - \frac{bm}{p}$; whence C I $= c - \frac{da}{p} - \frac{dz}{p} + \frac{bm}{p}$, or if $g = c - \frac{da}{p} + \frac{bm}{p}$; then will C I $= g - \frac{dz}{p}$; conſequently, $czz = 2\,ng - \frac{2\,dnz}{p}$; by corol. after the firſt problem; and if $dn = pq$; the ſquare root of this equation will be $cz + q = \sqrt{2cng + qq}$.

If O P is one fourth of the radius O A; that is, if the radius is the two thirds of the ſpan of the arch, then will A P $= p = \frac{3}{4}\,a$; and the right angled triangle O P E, gives P E $= d = \frac{1}{4}\,a\sqrt{15}$, and the right angled triangle A P E, gives AE $= b = \frac{1}{2}\,a\sqrt{6}$. But O E (a) is to P O $(\frac{1}{4}\,a)$ as the radius 100000 is to the coſine 2500 of the A O E, which is found to be 75 degrees and 32 minutes, or $75.5\frac{1}{3}$ degrees.

And ſince unity is to 3.14159, as the radius a is to the ſemi-circumference $3.14159\,a$; and 180 degrees is to $75.5\frac{1}{3}$ as the ſemi-circumference $3.14159\,a$, is to the arc $v = 1.32\,a$ nearly; this value of v being ſubſtituted into thoſe of n and m, gives $n = .37\frac{1}{4}\,aa$, and $m = .85578\,b$ nearly.

EXAMPLE.

Let $AP = 12$, then will $a = 16$, and if $c = 15$; then will $n = 95.04$, $m = 16.766$, $g = 21.777$, and if we take 63.36 the two thirds of the area 95.04, for the value of n, we get $q = 81.734$, and 48074.1683, for the ſum of the terms under the radical ſign, whoſe ſquare root is 219.258, from which ſubtracting the known term 81.734 and dividing the difference by 15, gives $z = 9.168$ or BC equal to 9 feet 2 inches.

PROBLEM VIII.

To find the thickneſs BC *of the piers, when the outſide is a right line parallel to the chord* AE, *of the inſide arc.* Fig. 6.

By the ſimilarity of the triangles OMG, APE, we have $PE\,(d) : AP\,(p) :: OM\,(b) : GM = \frac{bp}{d}$; and ſince GM and ME are equal, we get $\frac{bbp}{d}$ for the area of the triangle OGR, and as the area of the ſector OAE is $\frac{1}{2}av$, we have $2nd = 2bbp - adv$: But the ſolid deſcribed by the triangle OGR, about an axis paſſing through the center O parallel to AE, is $\frac{4rp}{3d}b^3$; and that of the ſector OAE deſcribed in that rotation $\frac{2}{3}raab$; therefore $3dmn = 2pb^3 - aadb$, by what has been ſaid before. And becauſe there

Plate II.

Fig. 2

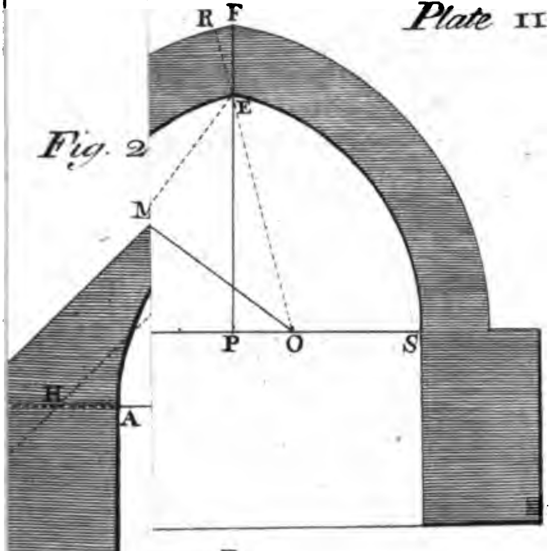
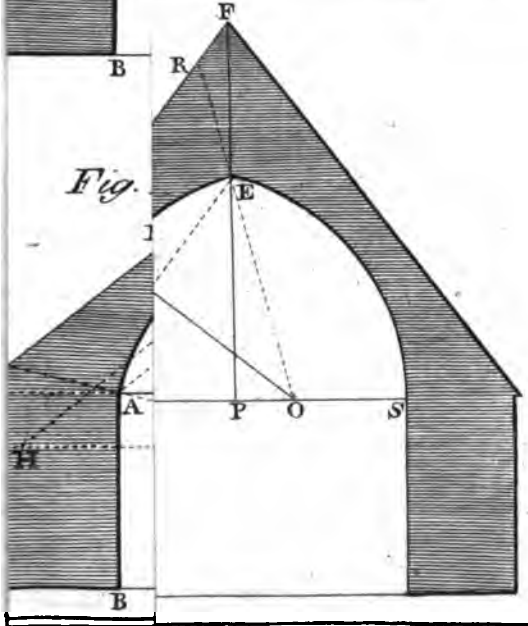


Fig.



J. Cowse Sculp.

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there is the ſame triangles here as in the laſt figure; we have $g = c - \frac{da}{p} + \frac{bm}{p}$, $dn = pq$, and $cz + q = \sqrt{2cng + qq}$ as before.

If we ſuppoſe again that O P is the three fourth of the radius O A; then will the values of p, d, b be the ſame as before, and hence $v = 1.32a$, $n = .55aa$, and $m = 1.092a$.

EXAMPLE.

Let $a = 16$, $c = 15$; then will $n = 140.8$, $m = 17.472$; $g = 22.876$; and if we take $93.8\frac{2}{3}$, the two thirds of the area 140.8 for the value of n; then will $q = 121.182$, and 79103.893 be the ſum of the terms under the radical ſign, whoſe ſquare root is 281.254, from which ſubtracting the known term 121.182, and dividing the difference by 15, gives $z = 10.67$ nearly.

N. B. We have neglected the ſpace E R F, in the two laſt figures, which could not be conſidered without rendering the operations very tedious and perplexed, and as in practice a ſcrupulous nicety becomes more troubleſome than uſeful, we aim more at ſimplicity than a too great mathematical ſtrictneſs wherever practice is concerned.

LEMMA I.

The diameter O L, *which biſects the chord* A E, *joining the extremities of the two ſemi-axes* A O, *and* O E, *of an ellipſis, biſects the area of the quadrant* A L E O. Plate III. Fig. 7.

For the diameter O L biſects all its ordinates which are parallel to that chord, as well as all the lines drawn in the triangle A O E parallel to the baſe A E; conſequently, the diameter L O biſects the area A L E O of the quadrant.

COR. I.

COR. I.

Hence, becauſe the tangent L H, is parallel to the ordinate A E of the diameter O L, by the nature of the ellipſis, and this diameter biſects A E in *m*, and ſince A O E is a right angle; A *m*, *m* O, *m* E, are equal; therefore the triangle O *m* A, is iſoſceles, and being ſimilar to the triangle O L H, this triangle is likewiſe iſoſceles; conſequently, O K = K H, and O L = L H.

COR II.

Hence the triangles A O E, O L K, are ſimilar, for the triangles O K L, H K L, having all their ſides equal, are equal in all reſpects: and ſince the triangle H K L is ſimilar to the triangle A O E, its equal OKL will be ſo too.

COR. III.

Becauſe O K : O A : : O A : O H, or 2 O K, by the laſt corollary; whence $OA = OK\sqrt{2}$; and by the ſimilarity of the triangles A O E, O K L; we have O A : A E : : O K : O L, and ſince $OA = OK\sqrt{2}$; we have $AE = OL\sqrt{2}$ by equality of ratio's.

PROBLEM IX.

To find the thickneſs B C *of the piers, when* G F, A E, *are two ſimilar elliptical quadrants, deſcribed from the ſame center* O, *and the joints are perpendicular to the tangent in that point.* Fig. 8.

If $OA = a$, $OG = b$, $OE = d$, and the reſt as before; then will $OF = \frac{bd}{a}$, by ſuppoſition, whence, ſince the circular quadrant deſcribed with the radius O G, O G, b, will be $\frac{1}{4} rbb$, and is to the elliptical quadrant O G F, as O G (b) to O F ($\frac{bd}{a}$) and therefore this elliptic quadrant will be $\frac{rdbb}{4a}$; and the quadrant O A E, will be $\frac{1}{4} rad$ by the ſame reaſon; therefore $4an = rd \times \overline{bb - aa}$, after having multiplied by $4a$.

Now becauſe raa, rbb, expreſs the areas of circles deſcribed by the radii O A, O G, in the rotation of the figure about the axis O F, and ſince the ſolids deſcribed by the elliptical quadrants in this rotation are the two thirds of the cylinders of the ſame baſe and altitudes, theſe ſolids will be $\frac{2}{3} raad$, $\frac{2r}{3a} db^3$, and their difference equal to $2rmn$ by remark the third, ſuppoſing OK $= m$; which gives $3amn = d \times \overline{b^3 - a^3}$, after having multiplied by $3a$. The firſt ſide of this equality being divided by $4an$, and the ſecond by its equal, gives $\frac{3}{4} rm = a + \frac{bb}{a+b}$.

If we imagine a quadrant of an ellipſis to be deſcribed through the center of gravity L, ſimilar to the former; then the direction L H, will be a tangent to the ellipſis, and therefore perpendicular to the joint paſſing through that point; and O K $=$ K H, by cor. I. or O H $= 2m$; hence D H $= a + z - 2m$; and by the ſimilarity of the triangles A O E, H D I, we have A O (a) : O E (d) : : D H : D I $= d + \frac{dz}{a} - \frac{2md}{a}$, and ſo C I $= c - d + \frac{2md}{a} - \frac{dz}{a}$; or if $g = c - d + \frac{2md}{a}$; we have $czz = 2ng - \frac{2ndz}{a}$, by cor. after prob. I. and if $aq = nd$, the ſquare root of this equation is $cz + q = \sqrt{2cng + qq}$.

E X-

EXAMPLE.

Let $a = 12$, $b = c = 15$, $d = 9$; then as $r = 3.142$ nearly, we get $n = 47.72$, $m = 8.629$, $g = 18.943$, and taking the two thirds of the area 47.72 for the value of n, we ſhall have $q = 23.86$ and 18648.4988 for the ſum of the terms under the radical ſign, whoſe ſquare root is 136.559, from which ſubtracting the known term 23.86, and dividing the difference by 15, we ſhall have $z = 7.513$, or BC equal to 7 feet 6 inches.

PROBLEM X.

To find the thickneſs BC *of the piers, when the outſide is a right line* GF, *parallel to the chord* AE *which ſubtends the elliptical quadrant.* Fig. 9.

If $AO = a$, $OE = d$, $OM = b$, Om or $Am = b$, and the reſt as before; then by the parallel lines AE, GF; we have $Om\,(b) : OE\,(d) :: OM\,(b) : OF = \frac{bd}{b}$; and $Om\,(b) : OA\,(a) :: OM\,(b) : OG = \frac{ab}{b}$; whence $\frac{abbd}{2bb}$ will expreſs the area of the triangle GOF, and ſince $\frac{1}{4}rad$ expreſſes the area of the elliptical quadrant, we have $4bbn = ad \times \overline{2bb - rbb}$, after having multiplied by $4bb$.

Now becauſe raa, $\frac{raabb}{bb}$, expreſs the circles deſcribed by the radii, OA, OG, in the rotation of the figure about the axis OF; we have $\frac{2}{3}raad$, $\frac{raadb^3}{3b^3}$ for the ſolids deſcribed by the quadrant OAE, and the triangle GOF, in that rotation; therefore their difference is equal to $2rmn$ by the third remark, which gives $6mnb^3 = aad \times \overline{b - 2b^3}$.

As the reſt of the figure is the ſame as before, we have $g = c - d + \frac{2md}{a}$, $aq = nd$, and $cz + q = \sqrt{2cng + qq}$, as above.

EXAMPLE.

Let $a = 12$, $d = 9$, $c = 15$; then will $b = 7.5$, and the diameter On = AE $\sqrt{2}$ by cor. 3. will be 10.6, and if we allow 3 feet for the thickneſs Mn of the arch; we have $b = 13.6$, whence $n = 92.72$, $m = 9{,}23$, $g = 19.845$; and if we take 61.812 the two thirds of the area 92.72 for the value of n, we get $q = 46.36$, and 38949.0238 for the ſum of the terms under the radical ſign, whoſe ſquare root is 197,355 from which ſubtracting the known term 46.36, and dividing the difference by 15, gives $z = 10.066$, nearly; which is 3.5 inches leſs than when the inſide is circular, this ariſes from the difference between the weights of the arches; for we found 112 feet in problem 3, and here only 92.72, ſo that either of theſe arches may be uſed as occaſion ſhall require.

But if $c = 9$, and the reſt as before; then will $z = 9.57$, which is very little leſs than what has been found in the third problem.

When both ſides of the arch is terminated by ellipſis, its piers require leſs maſonry, than when it is terminated by circles; for we found in the ſecond problem 8 feet 3 inches, and in the ninth 7 feet 6 inches, and therefore the difference is 9 inches: notwithſtanding Mr. *Belidor* found the contrary, and from thence concludes that the elliptic arch has a greater preſſure than the circular one: this would be true if the weights of the arches were equal; but we have found the area in the circular one to be 63.62 feet, and 47.72 feet in the ellipſis; and therefore the weight of the circular arch is to the weight of the elliptic arch, as 133 is to

109

.100 nearly. So that the weight of the firſt is about one third more than in the ſecond.

PROBLEM XI.

To find the thickneſs BC *of the piers when there are counterforts* VD; *the inſide of the arch being circular and the outſide a right line.* Fig. 10.

Let $CV = b$, be the length of the counterforts, which having the ſame height as the piers, and the interval from the one to the other, is to their thickneſs as two to one,

It is plain that the point C is no more that about which the piers muſt turn in order to be overſet, but it is the point V or extremity of the counterforts: ſo that the diſtance V I of the direction L I, muſt here be found on the line V R.

If we retain the ſame values as before, we get $n = .777\,aa$, $m = .756\,a$, and $OH = 2\,m$, by the third problem: whence $RH = a + b + z - 2\,m$, and $VI = c - a - b + 2\,m - z$, or if $g = c - a - b + 2\,m$; then will $VI = g - z$; therefore $2\,ng - 2\,nz$ will be double the momentum of the arch.

And ſince cz expreſſes the area of the pier CA, and $b + \frac{1}{2}z$, the diſtance of its center of gravity from the line RV, we have $cbz + \frac{1}{2}czz$ for its momentum; and the area cb of the counterforts multiplied by $\frac{1}{2}b$, gives $\frac{1}{2}cbb$ for its momentum, which being reduced in the ratio of 3 to unity, gives $\frac{1}{6}cbb$; therefore twice the ſum of theſe laſt momentums, muſt be equal to that above, by cor. after prob. 1, that is $czz + 2\,cbz + \frac{1}{3}cbb = 2\,ng - 2\,nz$; and if $q = n + cb$; the ſquare root of this equation will be $cz + q = \sqrt{2\,cng - \frac{1}{3}ccbb + qq}$.

EX-

EXAMPLE.

Let $a = 12$, $c = 9$, $b = 4$; then will $n = 112$, $m = 9.072$, $g = 11.144$, and $q = 148$; hence 43938.304 will be the ſum of the terms under the radical ſign, whoſe ſquare root is 209.614; from which ſubtracting the known term 148, and dividing the difference by 9, gives $z = 6.846$ feet nearly, or BC equal to 6 feet 10 inches, which is 14 inches only leſs, than what Mr. *Vauban* has given to his piers, the counterforts being the ſame.

If we ſuppoſe $c = 15$, and $b = 5$; the reſt being the ſame as before, we ſhall have $n = 112$, $m = 9.072$ as before, and $g = 16.144$, $q = 187$; whence the ſum of the terms under the radical ſign is 87337.84, whoſe ſquare root is 295.529, from which ſubtracting the known term 187, and dividing the difference by 15, gives $z = 7.235$ nearly, or BC equal to 7 feet 3 inches nearly, whereas Mr. *Belidor* finds but 3 feet one inch for the ſame thickneſs; which methinks might have given him reaſon to ſuſpect his theory, as differing ſo widely from Mr. *Vauban's* practice, although the latter did not deduce his rules from any theory, yet his great practice made him arrive generally pretty near the truth.

If we ſuppoſe the height of the piers c to be 9 feet, and the length b, 3 feet only, we ſhall find $z = 7.746$ or BC equal to 7 feet 9 inches nearly, which differs from the thickneſs given by Mr. *Vauban*, by 3 inches only; ſo that according to this theory, he made the length of his counterforts one foot more than is required.

Having conſidered that moſt practitioners are unacquainted with algebra, and being willing to render this book uſeful to every perſon employed in theſe works, we imagined that a table containing the dimenſions of the piers of different width of arches would be acceptable to many of my readers, we have inſerted the following one.

A TABLE containing the thickneſs of the piers of powder magazines.

	10	12	14	16	18	20	22	24	26	28	30	32	34	36
9	3.686	4.239	4.750	5.224	5.666	6.082	6.472	6.844	6.969	7.545	7.855	8.165	8.465	8.754
10	3.768	4.347	4.885	5.386	5.855	6.297	6.740	7.106	7.483	7.841	8.180	8.510	8.821	9.164
11	3.828	4.440	5.002	5.533	6.021	6.486	6.935	7.343	7.741	8.120	8.484	8.834	9.171	9.494
12	3.899	4.529	51.05	5.649	6.168	6.657	7.118	7.554	7.974	8.375	8.757	9.125	9.479	9.822
13	3.950	4.592	5.179	5.763	6.298	6.809	7.292	7.747	8.185	8.604	9.006	9.392	9.765	10.123
14	3.990	4.653	5.267	5.861	6.415	6.939	7.445	7.922	8.371	8.814	9.230	9.638	10.027	10.402
15	4.039	4.711	5.348	5.949	6.521	7.053	7.585	8.079	8.553	9.006	9.456	9.861	10.270	10.661
16	4.076	4.761	5.411	6.031	6.616	7.180	7.715	8.223	8,714	9.185	9.636	10.073	10.493	10.894
17	4.109	4.806	5.469	6.109	6.703	7.278	7.832	8.349	8.869	9.348	9.816	10.268	10.712	11.125
18	4.138	4.847	5.522	6.167	6.783	7.373	7.948	8.479	8.998	9.499	9.982	10.443	10.898	11.333
19	4.172	4.884	5,563	6.227	6.859	7.457	8.038	8.590	9.125	9.637	10.136	10.612	11.080	11.528
20	4.257	4.917	5.614	6.282	6.921	7.537	8.129	8.694	9.242	9.769	10.279	10.772	11.218	11.710

The firſt column 10, 12, 14, &c. expreſſes the width of the arches in feet; the reſt of the columns, the thickneſſes of the piers in feet and decimals, anſwering to their heights marked in feet in the vertical column 9, 10, 11, 12, &c. reſpectively from 9 to 20 feet.

It may be obſerved that the length of the counterforts, have here been made one ſixth part of the opening of the arch, or $3b$ is always equal to the radius a: which proportion we found to be moſt agreeable in regard to the thickneſs of the piers; for by making the counterforts longer, the piers of ſmall arches would become ſo thin, and the materials would thereby not join ſo well, which ought to be avoided.

Thoſe who are not verſed in Algebra, may depend on the dimenſions here given, and that the arches will be good and laſting, provided the work is well executed, and the materials good; it is however adviſeable to leave the centers ſtanding at leaſt for ſix months, in order to give time to the maſonry to ſettle and harden; which being done, the work will not fail afterwards.

PROBLEM XII.

To find the thickneſs of the piers, having counterforts when the inſide is an ellipſis.

Becauſe we have $6mnb^3 = aad \times \overline{b^3 - 2p^3}$ and $4bbn = ad \times \overline{2bb - rbb}$ by problem X; and $RH = a + l + z - 2m$, by the laſt problem, ſuppoſing $CV = l$; and by the ſimilarity of the triangles OAE, RHI, we have AO (a) : OE (d) : : RH : $RI = d + \frac{dl}{a} + \frac{dz}{a} - \frac{2dm}{a}$. Hence $VI = c - d - \frac{dl}{a} - \frac{dz}{a} + \frac{2dm}{a}$; or if $g = c - d - \frac{dl}{a} +$

[illegible], we get $VI = g - \frac{dz}{a}$, and therefore $2gx - \frac{2ndz}{a}$, will be double the momentum of the arch, which therefore is equal to double the momentum of the pier and counterfort, found in the laſt problem; that is, $czz + 2clz + \frac{1}{3}cll = 2gx - \frac{2ndz}{a}$; and if $q = cl + \frac{nd}{a}$; the ſquare root of this equation will be $cz + q = \sqrt{2cxg - \frac{1}{3}ccll + qq}$.

EXAMPLE.

Let $a = 12$, $d = c = 9$, $l = 4$; then will $n = 92.72$, $x = 9.23$ by problem X. whence $g = 10.845$, and $q = 105.54$; theſe values being ſubſtituted into the equation above, gives 28806.5628 for the ſum of the terms under the radical ſign, whoſe ſquare root is 169.72, from which ſubtracting the known term 105.54, and dividing the difference by 9, gives $z = 7.13$ feet.

This thickneſs of the piers exceed that, when the arch is circular by 3 inches only; but as the quantity of maſonry in the circular arch is to the quantity in the elliptic arch, as 112 to 92.72; or as 7 to 5.8 nearly; it is evident that the elliptic arch and piers together require leſs maſonry than the circular arch and its piers.

Since then the elliptic arch is rather ſtronger at its hanches than the circular one, and the middle or its weakeſt part, ſufficiently covered by maſonry; and as it is lower, and therefore better covered from the ſight of an enemy, it cannot be ſo eaſily deſtroyed; it is evident, that it may be uſed as well, and often with greater advantage, than the circular one.

PRO-

PROBLEM XIII.

To find the thickneſs of the piers of a circular arch when there is a wall A E F G *above the piers as it happens over the gates of a fortreſs.* Fig. 11.

The ſame thing being ſuppoſed as in the ſecond problem, and calling the thickneſs A E of the wall d, its height E F, b; then will db expreſs the area of the wall, which being multiplied by $z - \frac{1}{2}d$, gives $dbz - \frac{1}{2}ddb$ for its momentum, and as that of the pier is $\frac{1}{3}czz$, that of the arch $ng - nz$, by the ſecond problem, and therefore $czz + 2dbz - ddb = 2ng - 2nz$; and if $q = n + db$; we ſhall have $cz + q = \sqrt{2cng + cddb + qq}$.

N. B. It muſt be obſerved that $4n = rbb - raa$, $\frac{1}{4}rm = a + \frac{bb}{a+b}$, and $g = c - a + 2m$ by the ſecond problem.

EXAMPLE.

Let $a = 5$, $b = 7$, $c = 10$, $d = 2$, $b = 20$; then will $n = 18.852$, $m = 3.854$, $g = 12.708$, $q = 58.852$; and performing the operations indicated by the equation we ſhall find z, or the thickneſs B C of the piers to be 3 feet 3 inches nearly.

PROBLEM XIV.

To find the thickneſs of the piers when the arch is elliptical, the reſt being the ſame as before. Fig 11.

If the height within of the arch be called s; then will $4an = rs \times \overline{bb - aa}$, $\frac{1}{4}rm = a + \frac{bb}{a+b}$, $g =$

$c-s+\frac{2ms}{a}$, by the ninth problem; and $2ng-2nz$ will be double the momentum of the arch, which being made equal to double the ſum of the momentums of the pier and the wall, found in the laſt problem, gives $czz+2dbz-ddb=2ng-2nz$, or $cz+q=\sqrt{2cng+cddb+qq}$ by ſuppoſing $q=n=db$.

EXAMPLE.

Let $a=5$, $b=7$, $c=10$, $d=2$, $h=20$, as before, and the height $s=4$; then will $n=15.08$, $m=3.854$, $g=12.166$, $q=55.08$; and performing the operations indicated by the equation, we get $z=3.154$, which being ſomething leſs than the former, ſhews that either of theſe figures may be uſed, according as it is judged convenient.

PROBLEM. XV.

To find the thickneſs of the piers of a circular arch, when they have a given ſlope CD *on the outſide.* Fig. 12.

From the point C draw C E, and D F parallel to A B, and let the direction L H meet C E in I; then if BF $=z$, F C $=b$, and the reſt as before, the rectangle cz multiplied by $\frac{1}{2}z+b$, gives $\frac{1}{2}czz+cbz$ for the momentum of the part F A of the pier, and $\frac{2}{3}bbc$ will be the momentum of the part C F D, therefore $czz+2cbz+\frac{2}{3}cbb=2ng-2nz$ by the ſecond problem; and if $q=cb+n$, the ſquare root of this equation will be $cz+q=\sqrt{2cng-\frac{2}{3}cchb+qq}$.

The values of m and n are the ſame as in the fifteenth problem, and $g=c-a-b+2m$.

E X-

EXAMPLE.

Let $a = 5$, $b = 7$, $c = 10$, $h = 2$; then will $n = 18.852$, $m = 3.854$ as before, and $g = 10.708$, $q = 38.852$; whence the ſum of the terms under the radical ſign is 5279.5719, whoſe ſquare root is 72.66, from which ſubtracting the known term 38.852, and dividing the difference by 10, we get $z = 3.38$ nearly, and BC equal to 5.38 feet.

PROBLEM XVI.

The ſame thing being ſuppoſed to find the thickneſs of the piers, when the arch is elliptical.

The ſame denomination being ſuppoſed as in the fourteenth problem; then the values of m and n are the ſame here as there; and $g = c - s - \frac{sh}{a} + \frac{2sm}{a}$; therefore, if $q = \frac{sn}{a} + ch$, the reſt will be the ſame as in the laſt problem, that is $cz + q = \sqrt{2cng - \frac{2}{3}cchh + qq}$.

EXAMPLE.

Let $a = 5$, $b = 7$, $c = 10$, $s = 4$, $h = 2$; then will $n = 15.08$, $m = 3.854$, $g = 10.566$, $q = 32.064$; and performing the operations indicated by the equation, we ſhall have $z = 2.86$; and therefore BC will be 4.86 feet.

PROBLEM XVII.

Suppoſe a wall KOLM *to be continued above the arch with a ſlope on the outſide; to find the thickneſs* KP *or* LM, *the baſe* PO *of the ſlope being given.* Fig. 13.

Let PO $= d$, PL $= b$; KP $= z$; and the reſt as before; then zb multiplied by $\frac{1}{2}z + d$, gives $\frac{1}{2}bzz + dbz$ for the momentum of the part PM of the pier, and $\frac{1}{2}db$ multiplied by $\frac{2}{3}d$, gives $\frac{1}{3}ddb$ for the momentum of the other part OPL; the reſt being the ſame as in the fifteenth problem, and therefore $bzz + 2dbz + \frac{2}{3}ddb = 2ng - 2nz$; and if $q = n + db$ the ſquare root of this equation will be $bz + q = \sqrt{2nbg - \frac{2}{3}ddbb + qq}$.

EXAMPLE.

Let $a = 6$, $b = 8$, $c = 10$; $b = 16$, $d = 3$; then will $n = 22$ nearly, $m = 4.486$, $g = c - a - d + 2m = 9.972$, $q = 70$; and finiſhing the reſt of the operations indicated by the problem, we ſhall have $z = 2$ feet nearly; and therefore KO, is 4 feet.

Arches, as theſe are uſeful in building galleries behind the counterſcarps of ditches, ſuch as are made at *Bergen-op-zoom*, but when they are made pretty large, they become too high; for which reaſon I would chooſe to make them elliptical; and as we have all along found that their preſſure is rather leſs than that of the circular ones, on account of their having leſs weight; the ſame computations we made in regard to circular arches, will equally hold good in the elliptical ones.

PRO-

PROBLEM XVIII.

To find the thickneſs BF, *or* AD, *when there is a preſſure of earth againſt the outſide ſlope* CD. Fig. 12.

We have ſhewn in the firſt ſection of this work, that the preſſure of earth when compared to brick walls, was equivalent to $\frac{5}{54}$ parts of the cube of its height; and as theſe walls are commonly made of bricks, we have no more to do, than to add $\frac{5}{54}c^3$, to the momentum of the pier found in the ſeventeenth problem, in order to have the equation $cz + q = \sqrt{2cng - \frac{2}{3}ccbb + qq - \frac{5}{27}c^4}$, for this caſe.

EXAMPLE.

Let $a = 5$, $b = 7$, $c = 10$, $b = 2$; then will $n = 18.85$, $m = 3.854$, $g = 10.708$, as before in the fifteenth problem, and $q = 38.85$; theſe values being ſubſtituted into the equation, and the operations performed as indicated by the equation, gives $z = 2$ feet nearly, and therefore BC is 4 feet.

PROBLEM XIX.

To find the thickneſs of the piers, with counterforts, when there are two circular arches below, and a ſmall one above. Plate IV. Fig. 14.

The ſame denomination being ſuppoſed as in the eleventh problem, in regard to the lower arch, and let the ſame lines be drawn in the upper one; then if $oa = s$, OQ or $ro = f$, Qo or O$r = x$; u half the area of the ſmall arch, $ob = 2p$; then will $u = .777ss$ and $p = .756s$, by the eleventh problem: whence rb

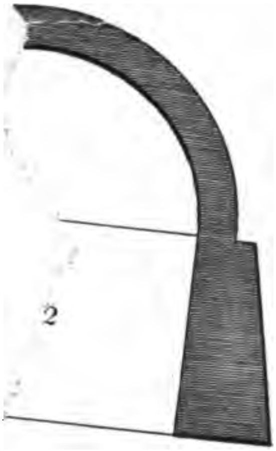
or $ri = f - 2p$; Oi or OH $= x - f + 2p$; RH *or*, RI $= a + b + z - x + f - 2p$; and VI $= c - a - b - z + x - f + 2p$; or if $y = c + x + 2p - a - b - f$; then will VI $= y - z$, which being multiplied by $2u$, gives $2uy - 2uz$ for double the momentum of the upper arch; this added to $2ng - 2nz$ double the momentum of the lower arch, and the ſum made equal to double the momentum of the pier and counterfort found in the before mentioned problem, gives $czz + 2cbz + \frac{1}{3}cbb = 2ng + 2uy - 2nz - 2uz$; whence if $q = cb + n + u$, the ſquare root of this equation will be $cz + q = \sqrt{2cng + 2cuy - \frac{1}{3}ccbb + qq}$.

EXAMPLE.

Let $a = 12$, $c = s = 8$; then if OQ $= f = 14\frac{1}{3}$; that is the lower arch, being three layers of brick thick; and the height P$o = 5\frac{2}{3}$; then will Q$o = x = 20$; $u = 49.728$, $p = 6.048$, $y = 9.763$, and $n = 112$, $m = 9.072$, $g = 10.144$, by the eleventh problem; hence we get $q = 197.728$, and 64700.98 for the ſum of the terms under the radical ſign, whoſe ſquare root is 254.363; from which ſubſtracting the known term 197.728, and dividing the difference by the coefficient, gives $z = 7.08$ nearly.

N. B. We have ſuppoſed the trilinear ſpace S between the lower and upper arch to be empty; that is without maſonry, beſides a ſmall ſpace between the roof and the pier of the upper arch has been neglected; but as it hardly can make any ſenſible difference in the thickneſs of the piers, the reader may depend on that found here to be ſufficiently exact for practice.

Plate III



o

7:1 2

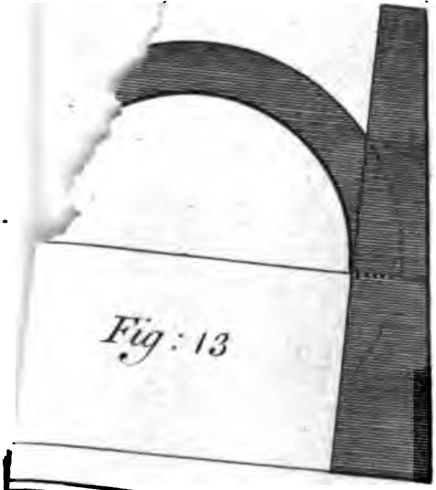


Fig: 13

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PROBLEM XX.

To find the thickneſs of the piers with counterforts, when there are two ſmall arches below, and a great one above. Fig. 15.

Let $ao = s$; the height V r of the lower piers, x; $u = .777ss$; $p = .756s$; then will $ob = 2p$, by the eleventh problem; and as $or = s + b + z$, we get rb or $ri = s + b + z - 2p$, and V $i = x - s - b - z + 2p$; or if $y = x + 2p - s - b$; then will V $i = y - z$, therefore $2uy - 2uz$, will be twice the momentum of the lower arch.

Now if we ſuppoſe the ſame values as in the eleventh problem, for the upper arch; that is $n = .777aa$, $m = .756a$, $g = c + 2m - a - b$; then will $2ng - 2nz$ be twice the momentum of the great arch; and therefore $czz + 2cbz + \frac{1}{3}cbb = 2ng + 2uy - 2nz - 2uy$; whence if $q = cb + n + u$; the ſquare root of this equation will be $cz + q = \sqrt{2cng + 2cuy - \frac{1}{3}ccbb + qq}$.

EXAMPLE.

Let $a = 15$, $c = 26$, $x = s = 6$, $b = 4$; then will $u = 27.972$, $p = 4.536$, $y = 5.072$, $n = 174.825$, $m = 11.34$; and $g = 29.38$, $q = 306.797$; now the operations indicated by the equation being performed, we ſhall have $z = 11.54$ feet.

Either of theſe two laſt problems may ſerve to conſtruct large powder magazines in the inland part of the country, where no enemy can come near them; for in fortified places, engineers chooſe to make ſeveral ſmall ones, ſo that if any one be deſtroyed by the enemy, the powder might not all be loſt, which would prove the loſs of the place at the ſame time.

If the arches were made elliptical inſtead of circular, they need not be ſo high, and a great deal of maſonry might be ſaved, as has been ſhewn in the twelfth problem.

PROBLEM XXI.

Let either of the exterior or interior curve of an arch be given to find the other ſuch, that all the arch-ſtones ſhall be in equilibrio with each other. Fig. 16.

Suppoſe the interior curve A *b c d* B be given, and let all the joints produced, meet in the ſame point C; from the centers of gravity *v*, *x*, *y* of the arch-ſtones, let the lines *v r*, *x s*, *y t*, be drawn at right angles to the horizontal line D Q drawn at pleaſure, and the latter interſecting the joints in E, F, G; then it is evident, that if D E, expreſſes the weight of the ſtone *v*, E F that of the ſtone *x*, and F G, that of the ſtone *y*; the line C D, will expreſs the force with which the ſtone *v*, preſſes the vertical joint H A; C E, the force with which the ſtones *v*, *x*, preſs the joint I *b*, and C F, the force with which the ſtones *x*, *y*, preſs the joint K *e*: for becauſe three powers are in equilibrio with each other, when they are as the ſides of a triangle which are perpendicular to their direction; and the ſide D E, is perpendicular to the direction *v r*, of the weight, and the ſides C D, C E, perpendicular to the directions of the forces with which the ſtone *v*, preſſes againſt the joints C H, C I: Again, E F, is perpendicular to the direction *x s*, of the ſtone *x*, and C E, C F, perpendicular to the directions of the forces with which the ſtone *x* preſſes the joints C I, C K; the ſame thing is true in regard to any other joint.

Since therefore the ſame line C E expreſſes the forces with which the ſtones *x*, *y*, preſs each other in contrary directions, they deſtroy each other; again as the ſame line C F, expreſſes the forces with which the ſtones *x*, *y*, preſs each other in contrary directions, they likewiſe deſtroy each other; and this is true in regard to any other two adjacent ſtones. Conſequently, if the weights of the ſtones are to each other as the lines D E, E F, F G, they will be in equilibrio with each other.

Whence, if the curve H I K L M be ſuch that the ſpace A H I *b*, be always equal to the correſponding triangle C D E, it will be that required, becauſe the height C D, of that triangle is given, its area will be as the baſe D E.

Now becauſe the circular ſectors deſcribed by the radii C E, C *b*, C I, in the ſame time, are as the ſquares of theſe radii, and ſince thoſe ſectors are likewiſe as the fluxions of the ſpaces CDE, CA*b*, CHI; and the difference between the two laſt is equal to the firſt, by what has been proved; the difference between the ſquares of the radii C I, C *b*, will likewiſe be equal to the ſquare of the radius CE.

Hence, when C E becomes C D, C I becomes CH and C *b* becomes C A: therefore the ſquare of C D is equal to the difference between the ſquares of the height C A, and C H at the key-ſtone, which being given, the line D Q will be given in poſition, and from thence the curve may be deſcribed.

Though we have ſuppoſed the interior curve given, yet it is manifeſt, the ſolution holds equally good when the exterior curve is given.

When the interior curve A B, becomes a right line parallel to D Q; the exterior curve H M, will alſo be a right line parallel to D Q. For becauſe C E will be to C *b* as C D to C A in this caſe; and therefore C E and C I will be in a conſtant ratio; *viz.* in the ratio of C D, to the root of the ſum of the ſquares of C D and CA. Which ſhews that flat ceilings made of ſtones, ſo as all the joints meet in the ſame right line, or flat arches, if we may call them ſo, will have all their ſtones in equilibrio.

PRO-

PROBLEM XXII.

To construct the exterior curve HM, *when the interior* AB *is given.*

Caſe 1. Let the interior curve AB be a quadrant of a circle, deſcribed from the center C with the radius CA or CB; and ſuppoſe the thickneſs AH or length of the key-ſtone to be given; then if BD be made equal to CH, and through the point D, the indefinite line DQ be drawn parallel to CB.

If after having drawn ſeveral radii CI, CK, CL, CM; interſecting DQ in E, F, G; you make one of the legs ae of a right angled triangle acg, equal to CA; and you take upon the other always $ce = CE$, $cf = CF$, $cg = CG$, and then $CI = ae$, $CK = af$, $CL = ag$; the curve paſſing through the points H, I, K, L, will be the required one.

For becauſe CA, CB, are equal by ſuppoſition, and CH, BD, by conſtruction, the ſquare of CD will be equal to the difference between the ſquares of CH, or BD, and CA; and ſince, CA, ca; CE, ce and CI, ac, are equal, the ſquare of CE or ce, will be equal to the difference between the ſquares of CI and Cb or CA; conſequently the curve HL is that required.

Fig. 17. Caſe II. Let the interior curve AB be a circular arc deſcribed from the center C, with the radius CB or CA, and let the part AH of the radius drawn through the vertex A, expreſs the given thickneſs of the arch in that place; on CH as a diameter deſcribe the ſemi-circumference of a circle HMC; take CM equal to CA, and in CA; CD equal to HM; and draw the indefinite right line DQ parallel to the horizontal [illegible] CB; then, after having taken upon one of the leg[illegible]l to CA, of a right angled triangle [illegible] and [illegible] other ce, cf; cg, reſpectively equal to the lines C E, C F, C G; and you make C I, C K, C L, equal to the correſponding lines *ae*, *af*, *ag*; the curve line H I K L paſſing through the points H, I, K, L, will be the required one.

For becauſe C M, C A and C D, H M are equal by conſtruction; the ſquare of C D is equal to the difference between the ſquares of C H and C A; and ſince we have alſo C A, C E, C I, equal to *ca*, *ce*, *ci*, reſpectively, it follows that the ſquare of C I is equal to the difference between the ſquares of C A, and C E; conſequently the curve H K L, has been rightly conſtructed.

This problem has been given at the beginning of the fifth ſection, book the third of our mathematical treatiſe, not only for arches generated by a parallel, but likewiſe for ſuch as are generated by a circular motion; which the reader is referred to, if he wants to know all the different caſes.

We have endeavoured in this ſection to give all the different problems that poſſibly can happen in practice, relating to this ſubject; and to render it of more general uſe, we have given the table of the dimenſions of piers for ſeveral openings of powder magazines; and though the arches are ſuppoſed to be circular, yet the ſame dimenſions may ſerve for elliptic; or parts of circles. For in all the different kinds of arches, the thickneſs of the piers of the circular one has always been found the greateſt, contrary to the erroneous notions of other authors; who have looked upon the circular one as the ſtrongeſt and the beſt, without being able to give any other reaſon than becauſe all the joints meet in the ſame point; not conſidering that the ſame thing is ſo in all arches, made of parts of circles: and as the fineſt bridges in *Europe* are built with elliptic arches, it is manifeſt, that they are able to ſupport the weight with which they are loaded: beſides we have ſhewn that they require about one third leſs maſonry,

ſonry; it muſt therefore be allowed that they are preferable to the circular ones, eſpecially when it is conſidered that they look more beautiful to the eye, and their ſlope is much leſs; which on the contrary is ſo very high in *Weſtminſter-Bridge*, that it is with the utmoſt difficulty, that heavy loaded carriages can get over it; though in many other reſpects, one of the fineſt in *Europe.*

It is alſo eaſy to ſhew that powder-magazines, made with elliptic arches, have the advantage over circular ones in many caſes. For in forts, or wherever the ramparts are low, it is impoſſible that circular powder-magazines can be built ſo low as not to be ſeen by the enemy from without, and therefore will endeavour to deſtroy it as ſoon as he can, knowing that the ſurrender of the place depends on it; and if they are built under ground, the powder can at leaſt no longer be kept in it than during a ſhort ſiege, otherwiſe it would ſoon grow damp, and loſe its ſtrength: whereas an elliptic arch may be made much lower. Nor will the ſhells have a greater effect upon theſe than on the others, becauſe the weakeſt part is ſufficiently covered with maſonry, ſo as to be in no danger; and as to the hanches, they are more curvated than the circular ones, and of conſequence are ſtronger in that place.

The two laſt problems are particularly uſeful in building of bridges, becauſe the arch-ſtones being in equilibrio with each other, it is manifeſt, that the bridge will be ſtronger, than when they are made in any other form: it is true that the upper part of a bridge cannot be made in this form, unleſs it is of one arch only; ſince the paſſage muſt have a regular aſcent and deſcent: yet nevertheleſs, the arch-ſtones being formed in this manner, and the reſt of the ſide walls being finiſhed in the uſual way, the overplus of the weight is not ſo very conſiderable as to produce any very great alteration in reſpect to the force of the arch ſtone.

pag. 64.

Plate IV

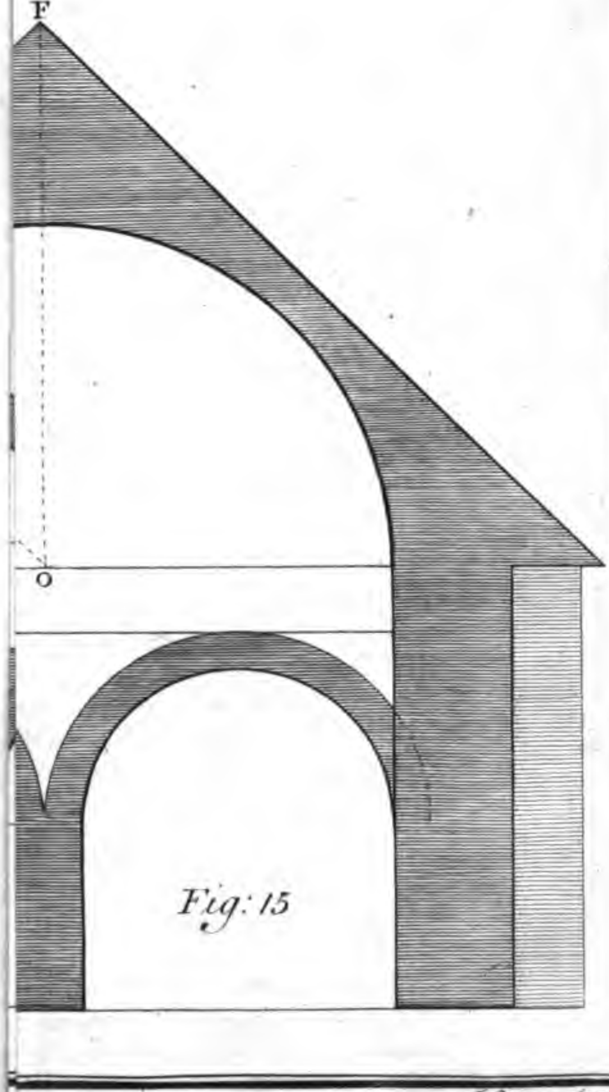

Fig: 15

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Beſides when a bridge is built otherwiſe, that is, in the uſual manner, the weakeſt part is loaded with a ſupernumerary weight, as well as the ſtrongeſt, whereby it remains ſtill the weakeſt, and if that part is more loaded in proportion than the reſt, the force to reſiſt that weight muſt be weakened: on the contrary, the greateſt part of the weight being in equilibrio, the remainder cannot cauſe ſo great a difference, as in the uſual manner.

SECT. III.

Of the STRENGTH *and* QUALITY *of* TIMBER.

AS the ſtrength and goodneſs of a building entirely depend on the well proportioning and uniting the whole together, in ſuch a manner, as every part thereof may be equally ſtrong; and as we have in the firſt ſection given tables of the thickneſs of walls which ſupport earth, of any height, and according to any ſlope, that may be uſed, as likewiſe ſhewn how to find the proper thickneſs of piers of vaults and arches of any form or opening; it remains now to treat of the different kinds of timber, and of their quality, as well as of their ſtrength, in reſpect to the different poſition in which they are made uſe of; eſpecially of thoſe moſt commonly employed in buildings; in order to render this work as uſeful as is poſſible, and thereby enable a young engineer to judge whether a building already executed, is compleat in all its parts, or when a building is propoſed, to make all its parts in due proportion, in ſuch a manner as to be every where equally ſtrong and good, and to avoid all needleſs expences; which is the point of greateſt perfection that can be attained in the art of building.

Of the NATURE *and* QUALITY *of* TIMBERS.

Of all the different kinds of timber known in *Europe* for building, oak is the beſt in all reſpects, becauſe when it is well ſeaſoned and dry, it is very tough and hard, it does not ſplit ſo eaſy as other timber, and bears a much greater weight than any other whatſoever; when it is uſed under cover, it never periſhes, no more than in water; on the contrary, the older it grows, the harder it becomes; and when it is expoſed to the weather, it exceeds all other timber whatſoever for durableneſs.

Fir timber is the next in degree of goodneſs for building, eſpecially in this country, where they build upon leaſes; for it laſts pretty long, when under cover, is very light, and is the cheapeſt timber that can be bought. It differs from oak in that it wants not ſo much ſeaſoning, and therefore no great ſtock is required before-hand: whereas oak muſt be kept at leaſt a twelve month, and the longer it is kept the better it is; on the contrary, fir is much ſtronger while the reſinous particles are not exilerated, than when it is very dry, as I have found by ſeveral experiments: Fir is uſed for flooring, above all other kind of wood, for wainſcoting and the ornamental parts of building within doors; it laſts likewiſe a great while under water; ſome pretend, that it never periſhes there, no more than oak.

Elm is the next wood in uſe, eſpecially here and in *France*, where it is plenty; becauſe it is very tough and pliable, it is eaſily worked, and does not eaſily ſplit, it bears driving of bolts and nails into it better than any other wood: for which reaſon, it is chiefly uſed by wheelwrights, and coachmakers, for ſhafts, naves, fellows, and other ſuch like things, and is almoſt the only kind of wood uſed in artillery.

Beach is alſo very uſeful upon many accounts; it is very tough and white when young, and of great ſtrength, but liable to warp very much when expoſed to the weather, and to be worm-eaten when uſed within doors; its greateſt uſe is to make planks of it, bedſteds, chairs, and other houſhold goods; and they uſe it likewiſe abroad, for axletrees, fellows, and in other wheelwrights works.

Aſh is likewiſe a very good wood, but very ſcarce in moſt parts of *Europe*, it ſerves in buildings, or for any other uſes where it is ſkreened from the weather; hand-ſpikes and oars are chiefly made of it, and indeed it is the only wood that is fit for this and any other things which require to be tough and pliable.

Wild cheſnut timber is by many eſteemed to be as good as oak, and ſeems to have been much uſed in old buildings; but whether theſe trees are not ſo common at preſent as they have been, or have been found not to anſwer ſo well as was imagined, it is certain that this timber is quite out of uſe at preſent.

There are beſides many other kinds of woods, which are eſteemed uſeful upon ſundry occaſions, ſuch as *Engliſh* and *Virginia* walnut, mahogony, cedar-wood, roſe and box-wood, for turners and cabinet-makers works; but as we intend to confine ourſelves to thoſe woods only which are uſed in building; ſo the following obſervations, ſhall extend no farther than to thoſe mentioned above.

Oak may be diſtinguiſhed into three ſorts, *viz.* that which grows on high gravelly ground, in thick foreſts, and that which ſtands on the ſkirts of foreſts, in hedges, or any where elſe, in damp or low ground, where the air has a free circulation.

That which grows on high gravelly ground, is of a reddiſh colour, not much unlike that of red ſand; it is very brittle, cuts very ſoft, rots ſoon, and is neither good for building nor burning; for it never produces any flame no more than if it was rotten, for which reaſon we ſhall ſay no more of it.

That which grows in thick foreſts, where the air has no free circulation, is very tall and ſtrait, without knots, ſplits eaſily, and has a very fine whitiſh grain; it is therefore very good for building, and for any other carpenters work; it makes exceeding fine planks for all ſorts of cabinet works, its natural colour and grain being ſo beautiful as no other wood can ſcarcely exceed; but as this wood is very tender and ſplits eaſily, it is not good for ſhip building, and therefore never to be uſed therein but when no other is to be had.

The third ſort, which grows in ſoft ground, and where the air freely circulates, is very hard and tough; it is never ſo tall nor ſo ſtrait and ſmooth as that in thick foreſts; but is the beſt that can be uſed for building of ſhips; eſpecially if it ſtands in a wet ſoil; I have ſeen ſome that grew in a damp meadow ground which was ſo tough as that the ſplinters would twiſt like ropes without breaking; if I miſtake not, this is the reaſon that the *Engliſh* oak is ſo much better for building ſhips than any other in *Europe*; becauſe the ſoil wherein it grows is generally damp, and low, and the foreſts are not ſo thick as they are elſewhere, by which the air circulates freely; whereas that which comes from *Norway* or other parts of *Germany* ſtands very thick and in great foreſts, for which reaſon it is ſo tender and ſo good for capenters and joiners work.

Fir may likewiſe be diſtinguiſhed into three different ſorts; the red, or yellow and the white, and a ſort between both. The red is by much the beſt and the moſt durable; becauſe it is much more impregnated with reſin or turpentine, which fills its pores, and prevents the water or dampneſs fromentering, and therefore is more able to withſtand the weather than the other: I believe that this is the ſort from which pitch and tar is extracted; this ſort is always uſed in works that are expoſed to the weather, and for ſtakes, to drive in the ground, but then it ſhould be burnt in the fire and pitched over while warm, which will preſerve it much longer; it has likewiſe been obſerved, that it does not decay under water; and it is the beſt for carpenters work.

The white ſort is not ſo ſtrong nor ſo durable, but is very good for the inſide of a building; ſuch as for flooring, doors, wainſcoting, and other ſuch like works; its colour and ſmoothneſs of grain makes it preferable for that uſe to the red ſort; as to the third ſort, it partakes of both qualities, is neither ſo ſtrong and durable as the red, nor ſo beautiful as the white; but ſerves well enough for all ſorts of timber in buildings where it is not expoſed to the weather.

As to the elm or aſh, I cannot find more than one ſort of each; yet it is likely that the different ſoils in which it grows muſt make it either tougher, and ſtronger, or brittle; as likewiſe that which grows in the open air muſt be ſtronger than that which grows in thick foreſts. For all timber and plants in general grow ſtronger in a free air, then where they are confined from it.

Beach, which grows in thick foreſts, if ſofter and more britle than that which grows in the free air; and is very white and tough when young; therefore wheelwrights uſe no other than what is very young, and what is no bigger than the ſcantlings require; eſpecially when uſed for axletrees, but for fellows they ſplit it into two only; but that which is ſawed into planks is much larger, and yet not too old, otherwiſe its grain is very coarſe and the wood becomes very brittle.

The goodneſs of timber not only depends on the ſoil and ſituation in which it ſtands, but likewiſe on the ſeaſon in which it is felled; in which architects diſagree very much; ſome will have it felled as ſoon as its fruit is ripe, others in the ſpring, and many in autumn or the fall of the leaves: and there are ſome who pretend that it ſhould be felled in the increaſe or full of the moon, imagining that all things increaſe in the ſame manner; but we ſhall leave theſe moon-blind gentlemen to their own lunatic judgment, and give the moſt rational opinions concerning the propereſt ſeaſon in which timber ought to be cut. Since ſap, as well as any other moiſtneſs, is certainly the cauſe that timber periſhes much ſooner than it otherwiſe would do; which appears from timber expoſed to the weather not laſting ſo long as that which is under cover, as likewiſe that dry timber, when uſed, is more durable than that which is freſh cut; this being the caſe, it is manifeſt that timber ſhould be felled when there is the leaſt ſap in it; which is from the time that the leaves begin to fall to the time that the trees begin to bud; that is from the middle of *October* to the middle of *March*; the greateſt number of architects agree with us, that this is the beſt ſeaſon for felling timber.

The weather has likewiſe an influence over timber; for if it be felled in damp and rainy weather, it will not dry, and if it lies too long in this ſtate, the ſap will moulder and cauſe the timber in time to rot: but if the weather be dry and fair, it is plain that the air will draw out the ſap and the timber will be more laſting.

When timber is cut, the bark ſhould be taken off and let lie for ſome time expoſed to the ſun and weather, and afterwards cut into rough ſcantlings nearly of the ſize they are intended to be uſed, and then laid up in ſtakes under cover to ſecure them againſt wet weather and the heat of the ſun; for the wet hinders it from drying, and the heat of the ſun ſplits it. As oak ſeems to contain more ſap than any other wood, and therefore requires a longer time to dry; the beſt way to make it ſoon fit for uſe, is, as ſoon as it is cut into ſcantlings, to throw it into water; this has been found by experience to draw out the ſap much ſooner than the weather; for the outſide will in a ſhort time grow as black as ink, which is a certain proof, that water draws out the ſap, in a ſhorter time than the air. As to the ſeaſoning of any other kind of timbers, I never heard of any other method, than to ſtake it up in piles, in ſuch a manner as that the air may freely paſs between; and to cover it from the rain and the heat of the ſun. The time required for drying timber before it is uſed is very uncertain, ſome ſorts require much more than others: oak muſt be kept a great while; for the dryer it is, the harder and ſtronger it grows: this we find by experience: for oak of an old building, or of a ſhip, is ſo hard ſometimes, that tools will ſcarcely cut it.

Beach requires likewiſe a great while drying; and if it is uſed before it is thoroughly ſeaſoned, it warps very much; and it may be obſerved in general, that the heavier the wood is the longer time it requires to dry: it may be known whether any timber is dry and ſound, by ſtriking with a hammer pretty hard at one end, and if it ſounds clear and diſtinct, you are certain that it is both ſound and dry.

Fir being a light wood requires leſs time to dry than any other ſort; fir ſcantling for roofing or for any other uſe within doors, ought to be half dry only; becauſe it is then ſtrongeſt, as we have found by ſome experiments, which ſhall be related hereafter; but as to the boards for flooring and wainſcoting they ought to be thoroughly dry, otherwiſe they ſhrink and ſpoil the work.

Timber ſhould likewiſe be cut when of a proper age; for when it is either too young or too old, it will not be ſo durable as when cut at a proper age. It is ſaid that oak ſhould not be cut under ſixty years old, nor above two hundred; whether this is right or not, it is very certain that all timbers ſhould be cut in their prime and nearly when full grown, and before it begins to decay; and that will be ſooner or later according to the dryneſs or moiſtneſs of the ſoil in which it grows: as alſo according to the bigneſs of the trees, and the kind of timber: there is therefore no certain rule to go by in felling of timber, but experience and judgment muſt direct here as well as in many more caſes.

Methods of computing the ſtrength of Scantlings.

Mr. *Parent* is the firſt that we know, who has treated this ſubject in a ſcientific manner, and in order to enforce his demonſtrations, he made ſeveral experiments, with various ſcantlings of oak and fir; by which he found that the ſtrength of an oaken ſcantling is to the ſtrength of a fir ſcantling of the ſame ſize as 5 is to 6: ſo that according to this experiment, fir wood is ſtronger than oak; Mr. *Belidor* has after him treated the ſame ſubject; and made likewiſe ſeveral experiments with oaken ſcantlings, but as to the experiment in reſpect to oak and fir, he took the foregoing proportion for granted. The ſame opinion, that fir is ſtronger than oak, has prevailed here; for, according to *Langley*, there was an act of parliament made, after the great fire in *London*, to ſettle the dimenſions of ſcantlings; in which thoſe of oak are always larger than thoſe of fir: But as this appeared to me contrary to ſenſe and reaſon, I reſolved to try the experiment myſelf, and found exactly the contrary, as will be ſeen hereafter. As Mr. *Parent* was a man of veracity and character, we cannot imagine that he affirmed more than what he really found; his oak muſt have been weaker and the fir ſtronger, than any I have met with; which led him into this error.

PROBLEM I.

To determine the ſtrength of a ſcantling whoſe dimenſions are given. Plate V[illegible] Fig. 1.

We ſuppoſe that all the fibres of the wood are ſtrait, and of the ſame ſtrength in its weakeſt part, that is, where it breaks; for it is no matter how they are elſewhere;

where; and that the fibres are the ſame in the ſame ſort of wood; altho' this is not ſtrictly true, yet it is ſufficiently near enough in practice ſo as to cauſe no ſenſible error.

Suppoſe the ſcantling ABC to be ſupported in the middle D by the edge of a triangular block R, and two equal bodies, P, Q, to be ſuſpended at A and C, equally diſtant from the middle B, of ſuch a weight as juſt to break the ſcantling.

It is evident that the weights P and Q will cauſe the ſcantling to bend at firſt ſo as to make a kind of a curvilinear angle at B, and then to break in that place, in a ſection BD perpendicular to either of the ſides AC: now as the power or force of theſe weights is more or leſs, according as they are ſuſpended farther from or nearer to the point fix D; theſe forces will therefore be in proportion to the products of the weights each multiplied by its reſpective diſtance from the ſection BD; or becauſe the weights and diſtances are here ſuppoſed equal, twice the product of one of the weights P multiplied by its diſtance, from the ſection BD, will expreſs the force of theſe two weights.

Having determined the force of the weights, we are now to determine the reſiſtance or ſtrength of the wood; which is done in the following manner. Let *acb* repreſent the ſection of the ſcantling; it is evident that this area repreſents the ſum of all the fibres to be torn or broken, and as they are all equal and of the ſame ſtrength by ſuppoſition; this area will expreſs the ſum of the ſtrength of all the fibres: but as the point D, or the baſe *ab* of the ſection is fix; and the directions of the fibres perpendicular to the area *acb*: the force or reſiſtance of each fibre is equal to the product of its ſtrength multiplied by its diſtance from the baſe *ab*: and therefore the ſum of all the fibres placed in the ſame line *df*, parallel to the baſe *ab*, multiplied by their diſtance *ad*, from that baſe *ab*, will expreſs their momentum or reſiſtance: What has been proved in regard to all the fibres placed in the line *df*, is equally true of all thoſe placed in any other line parallel to the baſe *ab*: and therefore the ſum of all theſe products will expreſs the total ſtrength or reſiſtance of the wood: But by a noted property of the center of gravity, the product of the area *acb*, multiplied by the diſtance of its center of gravity, from the baſe *ab*, will expreſs the total ſtrength or reſiſtance of all the fibres; or that of the whole ſcantling. Conſequently, having the ſtrength of any ſcantling of the ſame wood determined by experiment, that of any other may be found.

Fig. 2. If the ſcantling A C be ſupported at both ends by the triangular blocks P, Q, and the weight W, hanging in the middle B: then if we ſuppoſe the weights P and Q in the laſt figure to repreſent the blocks P and Q in this; and as each block ſupports half the weight W; it is evident that the weight W, multiplied by the diſtance A B or B C, will expreſs its momentum or force.

The ſame otherwiſe.

Since the weight W, is ſuſpended in the middle between the point fix; it is evident that each block ſupports exactly half the weight; and as the power or force of this weight on the blocks P, Q, is as the product of half the weight multiplied by the diſtance A B or B C of its direction from the point fix: It follows that the whole force of this weight is as twice the product of half the weight W multiplied by A B or B C: or as the whole weight W, multiplied by the diſtance A B, or B C.

COR I.

Hence, if the length A C of the ſcantling between the points fix A, C, be c; the area of the ſection s; the diſtance of its center of gravity, from the baſe d, and the weight W, w; then will $\frac{1}{2}cw$ expreſs the force of the weight W, and ds, the ſtrength of the ſcantling: therefore the momentum of the weight is to the momentum of the ſcantling as $\frac{1}{2}cw$ is to ds; or as w is to $\frac{2ds}{c}$; or if this ratio be given $w = \frac{2ds}{c}$.

From whence we may draw ſeveral uſeful conſequences, 1. The ſtrengths of two ſcantlings of the ſame wood, and of different dimenſions, or, which is the ſame, the weights they will bear, are to each other as the products of their ſections multiplied by the diſtances of the centers of gravity, from the baſe, divided by their lengths.

2. The ſtrengths of two ſcantlings of the ſame wood, which have the ſame length; are as the products of their ſections multiplied by the diſtances of their centers of gravity from the baſe.

3. The ſtrengths of two ſcantlings of the ſame wood which have equal ſections, are as the diſtances of their centers of gravity, divided by their lengths.

4. The ſtrength of ſcantlings of the ſame wood, whoſe diſtances of their centers of gravity of their ſections from the baſe are equal, will be to each other as their ſections divided by their lengths.

N. B. We have taken no notice of the parts of the ſcantlings at each end, which are beyond the points A, C, and which ſerve to ſupport them on the blocks; for they cauſe no difference in reſpect to their ſtrength: the ſame thing may be ſaid in reſpect to the weights of the ſcantlings, which are ſo ſmall in proportion to the weights they bear, that there is no occaſion of conſidering them; becauſe there is no geometrical exactneſs required, nor can be attained in practice. It may alſo be obſerved, that when the weight hangs between the point fix; the baſe to which the diſtance of the center of gravity is referred, is the upper ſurface A C; ſince it muſt open and break firſt at the lower D; whereas when the point fix is between the weight, as in the firſt figure, it is the lower ſurface.

COR. II.

COR. II.

Fig. 2. If the ſection of the ſcantling AC be a rectangle placed flat on one of its ſides, which we call b, and its height or other ſide a; then will ab, expreſs the area of the ſection; and the diſtance d of its center of gravity from the upper baſe, will be $\frac{1}{2}a$; therefore the equality found in the firſt corollary, $w = \frac{2ds}{c}$: becomes here $w = \frac{aab}{c}$. Which ſhews, that *the ſtrength of a rectangular ſcantling laying flat on one of its ſides; is as the product of the ſquare of its height multiplied by its baſe, and divided by its length.*

Hence a deal board of an inch thick and ten inches broad, being placed on its flat ſide, and then on its narrow ſide; the force in the firſt caſe will be to the force in the ſecond, as unity is to 10. For the force in the firſt caſe will be as 10 multiplied by the ſquare of unity; and in the ſecond as unity multiplied by the ſquare of 10; that is, as 10 is to 100; or as unity to 10. So that if it bears 50 pounds when it lies flat, it will bear 500 when it lies on the narrow ſide.

This ſhews the reaſon that all timbers in buildings are always placed on the ſmalleſt ſide; becauſe they will by this means bear a greater weight, than if they were placed otherwiſe; and therefore ſave a good deal of timber; and this in proportion as they are made higher.

EXAMPLE.

We may from hence likewiſe find, whether the proportions of ſcantlings commonly given by carpenters are right according to their length; for which we ſhall chooſe the dimenſions of fir-girders as appointed by act of parliament, after the great fire of *London*; which are as follows.

Now if we ſuppoſe, that the dimenſions of any one of theſe ſcantlings be right, as for example that of 10 feet long; then we may find thoſe of any other, whoſe length is given, in this manner. Since theſe ſcantlings ought to bear the ſame weight or to be equally ſtrong; the product of the ſquare 100 of the height multiplied by the baſe 8, gives 800, which being divided by the length 10 feet or 120 inches, gives $\frac{20}{3}$ which expreſſes the ſtrength of the given ſcantling, and therefore muſt be equal to the dimenſions of any other; $\frac{aab}{c} = \frac{20}{3}$.

Length	Breadth	Height
10	8	10
12	8.5	10
14	9	10.5
16	9.5	10.5
18	10	11
20	11	12
22	11.5	13
24	12	14

Now if we ſuppoſed the length c to be 12 feet or 144 inches, and the height a, 10 inches; then by ſubſtituting theſe values into the laſt equality, it becomes $\frac{20}{3} = \frac{100b}{144}$; and if 20 be multiplied by 144, and 3 by 100; the former product divided by the latter gives 9.6 inches for the baſe b, of the ſcantling; which is 1.1 inches more than that above.

In the ſame manner may be found the dimenſions of all the other ſcantlings, whoſe lengths and heights are the ſame, which gives the following table.

Length	Breadth	Height
10	8	10
12	9.6	10
14	10.1	10.5
16	11.6	10.5
18	11.9	11
20	11	12
22	9	13
24	9.8	14

The breadths of the ſame ſcantlings being compared, it appears that thoſe whoſe lengths are 10, 12, 14, 16, 18, 20, are too little in the former table, and thoſe of 22 and 24 feet long, are too great: which ſhews that practice alone is not ſufficient to determine the proper ſize of ſcantlings; and that without the application of mathematical principles, no great improvement can be expected in any mechanical art whatſoever; notwithſtanding what ignorant workmen would inſinuate.

As to the dimenſions of oaken ſcantlings given by workmen, we ſhall not compare them, till we have given the following experiments, we made with great accuracy, and upon which the reader may depend.

EXPERIMENT I.

The ſticks uſed in this experiment were 24.5 inches long, from one end to the other, and half an inch ſquare; they were laid on two truſſes well ſquared, and ſtood at 20 inches diſtant from each other; ſo that the length of the ſticks is to be conſidered to be no more than 20 inches; the remaining part ſerved only to reſt upon; the weight was ſuſpended in the middle with a ſtring, and being ſuch as juſt to break the ſticks, and are as marked underneath.

Two dry oaken ſticks	69 lb. 50.
A dry fir ſtick	46.
A dry elm ſtick	31.

The firſt oaken ſtick ſeems to have been thorougly dry; I had it from the dock, and likely was taken out of an old ſhip; the ſecond I had out of the warren as dry as could be had; the grain of the wood was ſtrait in both; but that of the firſt was finer than that of the ſecond, and of a deeper colour; which, if I am not miſtaken, denotes, that the tree was in its prime when felled.

The fir ſtick did not bend ſo much before it broke as the oak; it was of the reddiſh kind, and the ſtrongeſt that could be found: As to the elm it bent very much before it broke; and as this laſt is ſo weak, we did not think proper to try any more of it in the following experiments.

EXPERIMENT II.

Two oaken ſticks cut out of an old axletree	55 lb. 54.
An oaken ſtick cut out of a ſpoke of a wheel	56.5
Three fir ſticks out of the ſame piece	36 36 36
A fir ſtick of an equal ſection, whoſe baſe and height were as 2 to 3	42.5.

The oaken ſticks in this experiment had a coarſer grain than thoſe in the former, and ſeem to have been of an older tree; as to the fir ſticks no difference could be perceived, either in the grain, colour, or any thing elſe, from the former.

By theſe experiments it plainly appears, that oak is ſtronger than fir, contrary to thoſe made by Mr. *Parent*, and common practice: for the weakeſt oak is ſtronger than the ſtrongeſt fir in the firſt experiment: in proportion as 25 to 23: But thoſe in the ſecond experiment, make a much greater difference, *viz.* as 54 to 36; or as 3 to 2: And if the ſtrongeſt oaken ſtick in the firſt experiment be compared to the ſtrongeſt fir; the proportion will be as 69 to 46; or as 23 to $15\frac{1}{3}$; or as 3 to 2; that is the ſame as before; which is very conſiderable, and therefore deſerves to be taken notice of.

As the ſtrength of the ſame kind of wood varies very much, it is impoſſible ever to come to an exact knowledge of the juſt proportion between the ſtrengths of oak and fir; but we are certain that oak is the ſtrongeſt of the two.

As the leaſt proportion we have found, that 25 to 23, is very nearly equal to that of 9 to 8; ſo that by making the oak ſcantling leſs in that proportion, there will be no danger of their being too ſmall, only it muſt be noted, that oak ought to have been cut a twelvemonth before it is uſed, as we have obſerved before, whereas fir does not require above ſix months ſeaſoning.

As the laſt fir ſtick had the ſame length, and an equal ſection with the others, it is plain that its ſtrength is to that of one of the others, as the height of the firſt is to the height of the ſecond, by what has been proved before: and if x be the height of the laſt ſtick, then will $\frac{2x}{3}$, be its baſe, and $\frac{2xx}{3} = ab$, or becauſe a and b are each $\frac{1}{2}$ or .5: we have $\frac{2xx}{3} = .25$; or $xx = .375$; whoſe ſquare root gives $x = .611$, or .6 nearly; that is the ſtrength of the laſt ſtick is to that of any of the former as 6 is to 5: Now if we ſay as 6 is to 5, ſo is the weight 42.5, this ſtick bore to the weight 35.4 nearly, whereas it bore a weight of 36 pounds; this difference is inconſiderable, conſidering that the weight cannot be ſo nicely obſerved, to come within 2 or 3 ounces; and beſides, the ſticks were not ſo exactly of the given dimenſions, as that no difference might ariſe from thence. So that this experiment, conſidering ſo ſmall a difference, anſwered the theory pretty nearly.

Having determined the proportion between the ſtrength of oak and fir ſcantlings, it remains now to determine the dimenſions of oak girders, from thoſe of fir; in which we ſuppoſe that a ſcantling of fir, being 10 feet in length, 8 inches in breadth, and 10 high, is ſufficiently ſtrong, and from thence all the ſucceeding ones both of fir and oak have been determined.

TABLE I.

TABLE I. Containing the dimenſions of girders.

The lengths are expreſſed in feet, aud the breadths and heights in inches.

FIR.

Length	Breadth	Height
10	8	10
12	8	11
14	9	11.1
16	9	11.9
18	10	12
20	10	12.6
22	11	12.6
24	11	13.2

OAK.

Length	Breadth	Height
10	7	10
12	7	11
14	8	11.1
16	8	11.9
18	9	11.9
20	9	12.5
22	10	12.5
24	10	13

For, according to the equality $w = \frac{aab}{c}$, above, if $c = 10$ feet or 120 inches, $a = 10$, $b = 8$; then will $w = \frac{20}{3}$; and $\frac{20}{3} = \frac{aab}{c}$; now if $c = 12$ feet or 144 inches, $b = 8$; then will $\frac{20}{3} = \frac{8aa}{144}$, or $aa = 120$, whoſe ſquare root is 11 nearly, for the ſquare of 11 is 121. In the ſame manner are found all the fir ſcantlings: And if we reduce $\frac{20}{3}$, in the proportion as 9 to 8; we ſhall have $\frac{160}{27}$ for the ſtrength of oaken ſcantlings: that is $\frac{160}{27} = \frac{aab}{c}$.

Hence if $c = 10$ feet, $b = 7$; then will $\frac{160}{27} = \frac{7aa}{120}$, or $aa = 101$, whoſe ſquare root is 10 nearly; which is the ſame as in the table; the reſt of the oaken ſcantlings are found in the ſame manner.

TABLE II. Containing the dimenſions of fir joiſts common and trimming.

Common.

Length	Breadth	Height
6	2	8
8	2.5	8.2
9	3	8
10	3	8.4
11	3.5	8.1
12	4	8

Trimming.

Length	Breadth	Height
5	3	7
6	3	7.6
7	3.5	7.6
8	4	7.6
9	4.5	7.6
10	5	7.6

The dimenſions of the firſt ſcantling in each table, are ſuppoſed to be of a ſufficient ſtrength, and the reſt are from thence determined. For if $c = 6$ feet or 72 inches, $b = 2$, and $a = 8$; then will $\frac{16}{9} = \frac{aab}{c}$; and if $c = 8$ feet, $b = 2.5$; then will $\frac{16}{9} = \frac{2.5\,aa}{96}$, or $aa = 68.26$, whoſe ſquare root is 8.2; the ſame as above.

But if we ſuppoſe that $c = 5$ feet, $b = 3$, and $a = 7$, then will $\frac{49}{20} = \frac{aab}{c}$, by which the ſecond table is conſtructed. For if $c = 6$ feet, $b = 3$; then will $\frac{49}{20} = \frac{3\,aa}{72}$, or aa 58.8; whoſe ſquare root is 7.6, nearly.

TABLE III. Containing the dimenſions of fir bridging joiſts.

In ſmall Buildings.

Length	Breadth	Height
6	2.5	5
7	2.5	5.5
8	2.5	5.9
9	3	5.6
10	3	6
11	3	6.2
12	3	6.5

In large Buildings.

Length	Breadth	Height
6	3	5.4
7	3	5.8
8	3	6.2
9	3	6.6
10	3	7
11	3.5	6.8
12	3.5	7.1

If we ſuppoſe that $c = 6$ feet, $b = 2.5$, $a = 5$; then will [illegible] $= \frac{aab}{c}$, by which the ſecond table is conſtructed, and if $c = 6$ feet, $b = 3$, $a = 5.4$, then will $\frac{7.29}{6} = \frac{aab}{c}$, by which the ſecond table is conſtructed. It may be obſerved that carpenters always allow larger ſcantlings in large buildings than in ſmall ones, and they muſt be ſtronger, than barely to ſupport the weight they are to ſuſtain.

N. B. The reader will find the ſeveral names of the timbers mentioned in theſe tables explained in the latter part of this work, where we treat of timber frames and roofings.

TABLE IV. Containing the dimenſions of tie beams.

Fir.

Length	Breadth	Height
12	6	8
16	7	8.5
20	7	9.5
24	7	10.4
28	8	10.5
32	8	11.3
36	8	12
40	9	12
44	9	12.3

Oak.

Length	Breadth	Height
12	5	8.2
16	6	8.7
20	6	9.7
24	6	10.6
28	7	10.6
32	7	11.3
36	7	12
40	8	12
44	8	12.6

By following the ſame method as before, we ſhall find $\frac{8}{3} = \frac{aab}{c}$, for the equation by which the firſt table is conſtructed; and $\frac{7}{3} = \frac{aab}{c}$ nearly, for that by which the ſecond is conſtructed.

TABLE V. Containing the dimenſions of the principal rafters.

Of Fir.

Length	Breadth	Height
18	4	5.5
20	4	6.1
22	4	6.4
24	5	6
26	5	6.2
28	5	6.4
30	5	6.7
32	5	6.9
34	5	7.1
36	5	7.3
38	5	7.5
		7.7

Of Oak.

Length	Breadth	Height
18	3	6.3
20	4	5.7
22	4	6
24	4	6.3
26	4	6.5
28	4	6.8
30	4	7
32	5	6.5
34	5	6.7
36	5	6.9
38	5	7.1
40	5	7.3

Authors give various dimenſions to the principal rafters; Mr. *Smith* gives one ſort, Mr. *Price* another, and Mr. *Langley* will have them to be ſtronger at the bottom than above; but, his is not followed by any workmen, as I am told; beſides Mr. *Price* ſays, that they ſhould be ſtronger in large buildings than in ſmall ones, although of the ſame length; I ſee no reaſon for any ſuch practice; their ſtrength ought rather to be in proportion to the weight of the covering, and to the diſtances they are from each other: as authors do not agree in regard to the ſtrength of rafters, we have choſe a medium between them, for the dimenſions of the firſt ſcantling of each table.

TABLE VI. Containing the dimenſions of ſmall rafters.

Of Fir.

Length	Breadth	Height
9	2.3	4.7
10	2.4	4.9
11	2.5	5
12	2.6	5.2
13	2.7	5.4
14	2.8	5.5
15	2.8	5.6
16	2.9	5.8
17	2.9	5.9
18.	3	6
19	3	6.1
20	3.1	6.2

Of Oak.

Length	Breadth	Height
9	2.3	4.6
10	2.3	4.7
11	2.4	4.8
12	2.5	5
13	2.6	5.2
14	2.6	5.3
15	2.7	5.4
16	2.8	5.5
17	2.8	5.6
18	2.9	5.8
19	3.	5.8
20	3	6.

Theſe are the tables commonly given by carpenters and architects, concerning the dimenſions of ſcantlings; but as their exactneſs depend on the dimenſions taken out of other authors, of the firſt ſcantling of each table, ſo that if they are not right, all the reſt are likewiſe falſe; but as we always took the ſhorteſt, which are the likelieſt to have been uſed, and found to be of a ſufficient ſtrength, it is preſumed that the other ſcantlings given here are all ſtrong enough; and perhaps more ſo than they need to be.

EXAMPLE II.

Fig. 5. Let a rectangular ſcantling be placed edgeways, ſo that BD be the diagonal, and let the ſides ſtill be repreſented by a, and b; then will $d = \frac{1}{2}\sqrt{aa + bb}$; and therefore the equation $w = \frac{2ds}{c}$; becomes $w = \frac{2abd}{c}$ in this caſe; and ſince d or the diagonal BD is greater than any one of the ſides; the ſcantling will bear a greater weight in this poſition, than if it were placed flat on one of the ſides: But as wood will yield at the point B, by the force of the weight ſuſpended there; the ſtrength will be found ſomething leſs than is expreſſed by this equation.

EXAMPLE III.

Let the ſection of the ſcantling be a circle, whoſe diameter is a, and area s; then will $w = \frac{as}{c}$ be the equation, which ſhews that the force of a cylindric ſcantling, is expreſſed by the area of its ſection multiplied by its diameter, and divided by its length; and therefore is to the force of a ſcantling whoſe ſection is the circumſcribed ſquare; as the area of the circle to that of the circumſcribed ſquare.

It is alſo manifeſt, that the ſtrength of a triangular ſcantling, when laid flat on the baſe, is double the ſtrength when the edge is undermoſt, ſo as the baſe be parallel to the horizon. For the diſtance of the center of gravity from the baſe is half the diſtance of that center from the vertex.

PROBLEM II.

To find the weight a ſcantling A C *will bear, when it is ſuſpended any where between the points* A *and* C. Fig. 3.

Since the block P, which is neareſt to the point of ſuſpenſion B, ſupports a greater part of the weight than the block Q, which is fartheſt from it; we are to find the parts of the weight which each bears, in order to ſolve the problem. By the known rules of mechanics, the whole length A C of the ſcantling is to any part A B or B C, as the whole weight W, is to the part ſupported by the block Q or P. If therefore we call A B, m, B C, n, and the reſt as before; we have $c : n :: w : \frac{nw}{c} =$ to the part ſupported by the block P; and $c : m :: w : \frac{mw}{c} =$ to the part ſupported by the block Q: Whence theſe weights being multiplied by their reſpective diſtances A B, B C, give $\frac{nmw}{c}$, $\frac{nmw}{c}$, for their momentums, and the ſum $\frac{2mnw}{c}$ muſt be equal to the ſtrength ds of the wood by problem the firſt, which gives $\frac{2nmw}{c} = ds$, or $w = \frac{cds}{2nm}$ for the weight required.

If we ſuppoſe the weight to be ſuſpended in the middle, then will $n = m = \frac{1}{2}c$; and the laſt equation becomes $w = \frac{2ds}{c}$; which is the ſame as in the firſt problem.

If the ſcantling A C is rectangular, and its baſe be b, altitude a; then will $ab = s$, and $d = \frac{1}{2}a$; theſe values being inſtituted into the equality above, gives $w = \frac{aabc}{4nm}$.

Since, when the weight is ſuſpended in the middle, we have $w = \frac{aab}{c}$; it is evident, that the ſtrength of the ſcantling when the weight is ſuſpended in the middle, is to the ſtrength of the ſame ſcantling, when the weight is ſuſpended nearer to one end than the other, as $4nm$ is to cc: Conſequently the weight any ſcantling will bear when ſuſpended in the middle being known; the weight which that ſcantling would ſupport at any diſtance from either end, may be found by the laſt proportion.

EXAMPLE.

Let A C be 20 inches, and the ſection half an inch ſquare; ſuppoſe the ſcantling to be of fir, ſuch as we uſed in the ſecond experiment, which bore 36 pounds; and let A B be 5 inches; then will B C be 15; whence $4nm = 300$, and $cc = 400$; therefore 300 : 400 : : 36 : 48 = to the weight the ſame ſcantling would bear being ſuſpended at the diſtance of 5 inches from either end.

This ſhews, that in buildings, it ſhould be avoided as much as poſſible, to place the weight in the middle of a beam, ſuch as king-poſts are in roofs; and therefore it is more advantageous to uſe prick-poſts inſtead of king-poſts; this is likewiſe what carpenters do in moſt buildings where there is no partition wall to ſupport the beam in the middle.

Fig. 4. It may likewiſe be obſerved, that a ſcantling A C of the ſame ſtrength with the former, will bear two weights W, W, each of 48 pounds, when their diſtances A E, F C from the ends are 5 inches:

this appears plain from the foregoing example, becauſe theſe weights will cauſe the ſcantling to break in two places.

Mr. *Parent* is the firſt we know, that has ſhewn how to cut the ſtrongeſt ſcantling poſſible, out of a given tree: As this may be uſeful in practice, becauſe timber merchants are ſenſible that the ſquare is the greateſt figure that can be inſcribed in a given circle, and for which reaſon they chuſe to make all their timbers ſquare, as being moſt advantageous to them; we ſhall inſert the following

PROBLEM III.

Let A F B E, *be the circumference of a tree out of which it is propoſed to cut the ſtrongeſt rectangular ſcantling that is poſſible.* Fig. 8.

Draw the diameter D G, at right angles to the parallel ſides A E, B F, interſecting A E in P; then becauſe the ſtrength of the ſcantling is expreſſed by $AE \times AE \times AF$, as has been proved in the firſt problem; but by the property of the circle, we have $\overline{AP}^2 = DP \times PG$, and $AF = 2\,CP$; therefore the ſtrength of the ſcantling will likewiſe be expreſſed by $8\,DP \times PG \times CP$; now becauſe this expreſſion is the greateſt of all poſſible, when the ſquare of C P is one third of the ſquare of C D, by article 550 of our *Elements of mathematics*; or which is the ſame, when the ſquare of the baſe A F is one half of the ſquare of the altitude A E: For becauſe the ſum of the ſquares of C P and P A, is equal to the ſquare of the radius C D, by the property of the circle: and therefore if the ſquare of C P is one third; the ſquare of P A will be the two thirds of that ſquare, and conſequently, the ſquare of AP muſt be double the ſquare of C P; or the ſquare of A E double the ſquare of A F.

CON-

CONSTRUCTION.

Fig. 7. Divide the diameter A B of the tree into three equal parts at C and D; and from the points C and D of diviſion, draw D E perpendicular above, and C F, below the diameter; then if the points of interſections E, F, of theſe lines and the circumference, are joined to the extremities A, B of the diameter; the rectangle A E B F, will be the greateſt that can be inſcribed in that circle.

For becauſe A D is two thirds, and D B one third of the diameter A B by conſtruction, the ſquare of D E, will be two ninths, and the ſquare of A D four ninths of the ſquare of the diameter; therefore the ſquare of A D is double the ſquare of D E; and by the ſimilarity of the triangles A D E, A E B; the ſquare of A E is double the ſquare of E B.

It has been obſerved a great while, that when the baſe of a ſcantling is to its height as 5 to 7; that it was nearly the ſtrongeſt of all the ſcantlings whoſe ſections are equal, and are inſcribed in a circle; and becauſe the ſquare of 5 is 25, and that of 7 is 49; the former being nearly half the latter, exceeding by an unit only; this obſervation perfectly agrees with what has been proved in the laſt problem.

PROBLEM IV.

If a ſcantling be ſupported at the ends by two blocks P, Q, *not placed in the ſame horizontal line, and the weight ſuſpended in the middle, to find the ſtrength of this ſcantling.* Fig. 9.

From the point C in the vertical line, paſſing through the edge of the higheſt block Q, draw C E parallel to the horizon, meeting the direction of the weight in L, and the vertical line drawn through the edge of the lower block P in E; then becauſe it has been proved in the firſt problem, that the weight W multiplied by the diſtance of its direction from one of the points fix, expreſſes the momentum or force of that weight: that is W × C L expreſſes the momentum: but the force of the wood has likewiſe been proved to be as the product of the ſection multiplied by the diſtance of its center of gravity from the point B. Therefore if we call C E, n, and the reſt as before; we ſhall have $\frac{1}{2}nw = ds$, by what has been proved before, conſequently $w = \frac{2ds}{n}$.

Hence, becauſe we have $w = \frac{2ds}{c}$, when the ſcantling lies horizontally, and c expreſſes its length: the ſtrengths of the ſcantling in theſe different poſitions, are to each other reciprocally as the diſtances of the directions of the weight from one of the points fix; that is the ſtrength of the ſcantling in this oblique poſition is to its ſtrength in a horizontal poſition, as C B is to C L; or as the radius is to the coſine of the inclination L C B.

For example, if the ſcantling A C bears a weight of 36 pounds, when placed horizontally; to find what weight it will bear when it makes an angle of 15 degrees; then becauſe the coſine 9659 of that angle is to the radius 10000, as the weight 36 is to a fourth term, which gives 37.2 pounds nearly.

But if the angle of inclination is 60 degrees; then becauſe the coſine of this angle is to the radius as 5 is to 10; the ſcantling will ſupport a weight 72 double the former. Whence it is plain, that as the angle of inclination increaſes, ſo the ſtrength of the ſcantling increaſes likewiſe: and when that angle becomes a right one, or the ſcantling becomes upright, its ſtrength is not to be expreſſed. But becauſe the fibres of wood are not always ſtrait, and give way when preſſed very hard, it is very poſſible to preſs an upright ſcantling ſo as to give way and break.

This problem is uſeful in finding the reſpective ſtrengths of ſcantlings which are joined together, with different angles of inclinations; ſuch as in the roofing of any building, and thereby ſave unneceſſary expences.

Fig. 10. It is not ſufficient that the ſtrength of ſcantlings may be found, there are likewiſe ſome poſitions that are more advantageous than others, which ought likewiſe to be known. For inſtance, let ABC be the pitch of a roof, and a ſtrut E F, is to be placed ſo as to ſupport the rafter A B in the beſt manner: I ſay that when E F, is the baſe of an iſoſceles triangle AEF; or, which is the ſame, when it makes equal angles with the tie-beam A C, and the rafter A B, it is in its moſt advantageous poſition; for the ſtrength of this piece is proportional to the diſtance of its direction from the point fix A; but the perpendicular drawn from the point A to the baſe E F is the greateſt of all when the triangle is iſoſceles: Conſequently, this is the beſt poſition that the piece can have.

But if the ſtrength of the tie-beam AC, is to be conſidered, and there is no party wall to ſupport it in the middle, the caſe is otherwiſe; for in that caſe the piece muſt be upright as G H; becauſe the nearer the point G approaches the point fix C, the leſs ſtrength is required to ſupport the piece G H. Hence it is manifeſt, that a ſcantling may be moſt advantageouſly placed in reſpect to its own ſtrength, but not in regard to other ſcantlings to which it is joined: And conſequently, in the framing of timbers for a building, not only regard muſt be had to the ſtrength of the ſcantlings themſelves but likewiſe to thoſe to which they are framed.

PRO-

PROBLEM V.

To find the ſtrength of the principal rafters AB, BC, *ſo as to be proportional to that of the tie-beam* AC. Fig. 10.

Let the baſe of the rafters be x, and their height $2x$, that is double the baſe as they commonly are made: Let the baſe of the tie-beam AC be b, its altitude a, and half its length AD, n; then the ſtrength of the rafter will be expreſſed by $\frac{4x^3}{n}$ by the laſt problem; and that of the tie-beam by $\frac{aab}{2n}$ by the firſt problem; therefore $\frac{4x^3}{n} = \frac{aab}{2n}$ by ſuppoſition, or $8x^3 = aab$; whence the cube root will be $2x = \sqrt[3]{aab}$.

Hence becauſe the length AB of the rafters does not enter into the equation; it is evident, that whatever the pitch is, the cube root of the baſe of the tie-beam multiplied by the ſquare of its height, will always give the height of the rafter. For example, a fir tie-beam of 12 feet long, is made 6 inches by 8, according to the tables given before; then becauſe $a = 8$, $b = 6$; we get $aab = 384$, whoſe cube root is 7.2 inches nearly; for the height of the rafters, and hence we get 3.6 inches for the baſe.

If the beam AC be 24 feet long; then the baſe is 7 and height 10.4, according to the foregoing tables: whence $b = 7$, $a = 10.4$; and hence $aab = 757.12$, whoſe cube root gives 9.1 inches nearly, for the height, and 4.5 for the baſe of the rafters.

In the true pitch of a roof the principal rafters are the three fourths of the tie-beam, which being here ſuppoſed to be 24 feet long; and therefore the length of the principal rafters, will be 18; and according to the fifth table, their baſe is 4 and height 5.5; which dimenſions are therefore in no proportion to that of the tie beams. But then it muſt be conſidered, that the rafters are always ſupported by ſtruts or uprights, which bearing a part of the roof, ſtrengthens them and weakens the tie-beam.

Theſe are nearly all the different problems we could think of, that may be uſeful in framing of timber works; which the reader ought to be well acquainted with, if he deſigns to make any progreſs in the art of building, for what is found in moſt authors on architecture, relates chiefly to practice, which alone is not ſufficient to make any improvements; and it is no wonder, that for ſo many ages as architecture has been cultivated, there has been ſo little progreſs made, ſince very few had any knowledge of thoſe parts of the mathematics, which are neceſſary to be known, and therefore I adviſe the reader to make himſelf maſter of, before he enters upon the practice.

The theory of timber given here is of very great uſe both in civil and military architecture, ſince we are taught thereby not only how to find the proper ſtrength of ſcantlings in reſpect to their length, when placed in an horizontal poſition, but likewiſe when framed together, according to any angle of inclination, which practice alone could never have determined, to any degree of exactneſs: the entering into all the different applications that may happen in practice, would require more room than can be allowed in ſo ſmall a tract as this; for which reaſon, we ſhall give as much of it hereafter, as will be ſufficient to young engineers, for whom this work has been publiſhed.

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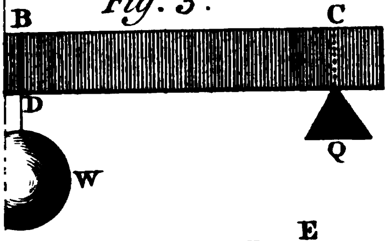
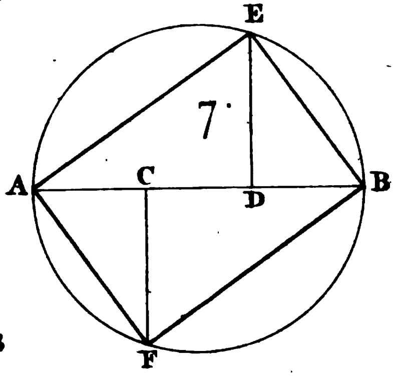
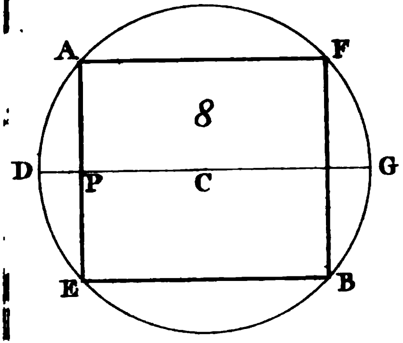
Plate V

Fig: 3.







J. Couse Sculp.

UNIV. OF MICH.

PART II.

Containing the Knowledge of the Materials, their Properties, Qualities, and Manner of uſing them.

BEFORE we enter into the manner of building the ſeveral works of a fortreſs, it is neceſſary to be particularly acquainted with the ſeveral materials of which they are compoſed, in order to diſtinguiſh their good and bad qualities, how to prepare and uſe them, in the beſt manner, that the works may be durable and laſting; which ought in all ſuch great undertakings be the principal view of an engineer, who is anſwerable for its ſucceſs or miſcarriage; this he is by no means able to perform without having a thorough knowledge of all the materials of which it is compoſed: But as theſe materials differ in their qualities in different parts of the country, where they are to be uſed; we ſhall explain firſt their general properties, and afterwards in what they differ in different places.

SECT. I.

Of the QUALITY *of* STONES *ſuch as are uſed in* BUILDINGS.

STONES may be diſtinguiſhed into two ſorts, that is into hard and ſoft; the hard ſtone, is that which is expoſed to the open air, ſuch as rocks, and thoſe which lie looſe upon the ſurface of the earth, and in ſeparate blocks: the ſoft ſtone is that which is found in quarries and under ground; it is undoubtedly true that the hardeſt ſtones make the moſt-laſting works; but as there is ſeldom a ſufficient quantity of them, to build the whole fortification, the beſt ſerve in the facings of the works, in the foundations, and wherever, the works are bathed with water: for as the foundations ſupport a great weight, they muſt be made ſtrong accordingly, or elſe the works will ſoon be deſtroyed: therefore the outſide of rocks or the upper ſtones of quarries, being the hardeſt, are uſed for that purpoſe.

Altho the ſtones of ſome quarries are very ſoft and eaſily worked when they are freſh taken out, yet when expoſed for ſome time in the open air become very hard and durable: therefore an engineer, who is employed in any particular place, may at all times know by the inhabitants, which of the quarries, if ſeveral, produces the beſt ſtones; he may likewiſe find by the buildings of ſome ſtanding, the quality of them; this will enable him to reſerve the beſt for ſuch works as require moſt ſtrength, and the ſofter ſort may be uſed in the inſide of the walls: but where there is but one quarry, he muſt examine whether ſome part is not better than others; in ſhort, a judicious choice of the materials, properly adapted, may render a building more laſting, than uſing them promiſcuouſly, as careleſs builders frequently do.

But if it happens that there is no quarry which has been opened long enough, ſo as to judge of the goodneſs of the ſtones, or where he is obliged to open new ones, he ought to expoſe the ſtones for a twelve month, × at leaſt, to the weather, both to heat and cold, before he imploys them; then if they do not ſplinter after a froſt, or do not moulder into dirt, when rubbed, he may be aſſured that the ſtone is good: and on the contrary, if they ſplinter or moulder, it is a certain proof of their bad quality.

× there is
a much
shorter way
to find if
ye Stones are
of a nature to
be destroyed
by the influence
of ye air &c
which is to
put a small piece in a Glass of Water mixt with
a sixth part Spt. of Nitre. if it dissolves ye Stone
[illegible] air will also have a destructive power on it; but if ye
[illegible] of Stone remains sev[illegible] in the liquor without
[illegible] will have little or no -

Mr. *Boyle* pretends, as he has been informed by workmen, that there is a ſap in ſtones as well as in timber, by which the ſame ſort of ſtone and taken out of the ſame quarry, if dug at one ſeaſon, will moulder away in a very few winters; whereas if they are dug at another ſeaſon, it will reſiſt the weather for a great many years, not to ſay ages: but as he does not mention what ſeaſon is beſt, nor gives any reaſon for what he advances; no rule can be gathered from what he ſays: we may ſay thus much, that they ſhould always be dug in the ſpring, ſo as they may have time to dry before the cold weather comes in: for the heat of the ſun will extract the greateſt part of the moiſture which otherwiſe expends in froſty weather, cauſes the ſtone to ſplinter, as it has been obſerved to do; altho' the ſtone is otherwiſe hard and good.

The ſame author ſays likewiſe, that ſome ſort of ſtones will decay in a few years; and others will not attain their full hardneſs in thirty or forty years, nay even in a much longer time; and beſides that there are quarries in ſome places of ſolid and uſeful ſtones, that, though being dug at a certain ſeaſon of the year, prove good and laſting, yet when employed in a wrong time, moulder away, and periſh in a few years. That there appears a ſeminal ſpirit, if I may call it ſo, in ſtone, is very probable; but what effect it has upon the ſtone when ſeparated from its ſtock is very uncertain, and therefore cannot be known but by a ſtrict inquiry of a long courſe of practice.

The manner of drawing the ſtones out of quarries, requires particular notice to be taken: for almoſt all ſtones lie in horizontal beds or ſtratas; that is, they cleave in that direction; and they have likewiſe a breaking one, which is perpendicular to the former, both which directions muſt be obſerved. The method of drawing ſtones out of quarries is thus: having uncoped it; that is, having removed the earth from the ſtone, it muſt be obſerved where it will cleave, and there drive in a good many wedges gradually together, till

influence over it for its

it is looſened from the rock, which being done, you next proceed to break it, which is performed in this manner; you mark the breadth of the ſtone with a ruler, and then cut a ſmall chanel in which a number of wedges are drove, from four to ſix inches diſtant from each other, ſlowly and all together, leſt the ſtone ſhould break acroſs and not according to the mark; but it may be obſerved, that this method is not always to be uſed, becauſe all the parts of a ſtone are not always of an equal hardneſs, but in ſome places it may be hard and in others ſoft, which is perceived in the cutting the chanel, and thoſe wedges which are in the ſofter parts, are drove deeper than the other, in ſuch a manner that all the wedges may preſs alike: this has been found by experience to be the beſt way of breaking ſtones.

Having thus broke them in length, which the ſtonecutters can do, as they pretend, to any ſize within leſs than half an inch, which is ſufficient for any rough ſtone; then you proceed to break them in breadth in the ſame manner as before in length. When theſe precautions are taken, the firſt expence is greater than if they were broke any how; but then there is little waſte in the ſtones, the workmanſhip will be leſs, and ſaves expences in the carriage.

But when the ſtone is very hard they will not cleave ſo eaſily; for the workmen are then obliged to cut a pretty deep chanel, and ſo wide as to lay two iron bars in it, and to leave room beſides for the wedges to be drove in between them, by which means the ſtones may be broken, which could not be done otherwiſe.

The workmen make at other times uſe of gunpowder to blow them up; which is performed in this manner: they make a ſmall hole with a chiſle, of an inch or a little more in diameter, ſometimes vertically, and at others horizontally, as it moſt convenient, and as deep as they want to blow up ſtones; this hole being cleaned clear of all duſt and rubbiſh, they put in ſome powder, then the reſt of the cavity is filled with the ſame ſtone beat into duſt, and rammed in as ſtrongly as they can; in doing that they place a wire in the middle, to preſerve a vent to ſet fire to the powder, and the rammer is hollow in the middle to receive this wire; this being done, and the powder fired, breaks off as much ſtone as they pleaſe; and the pieces are broken into ſuch blocks as are wanted. This way of breaking them is much cheaper than any other, but waſtes a great deal more ſtone, for which reaſon it is never uſed but where it is ſo plenty as that the ſmall pieces are no loſs, and which may ſerve as rubble to fill up the inſides of walls.

There are ſeveral kinds of ſtone; as marble, fire ſtone, purbeck ſtone, ray ſtone, alabaſter, free ſtone and common ſtone: of each we ſhall ſay ſomething in their order.

Marble is of various colours, as white, black, grey, green, ſome varied with ſpots and veins like the roots of trees; their nature and uſe are two well known to require any explanation; the marble found in England is moſtly black, and ſo very hard and difficult to poliſh, that very little uſe is made of it, than to burn and make lime; which is frequently done about *Plimouth*, where ſcarcely any other lime is uſed, as I am informed.

The fire ſtone comes from Reygate, and ſerves chiefly for chimneys, hearths, ovens, and ſtoves, being a dry porous gritty ſtone, which bears the heat without breaking, and it is, I ſuppoſe, on account of this quality that it has the name given of fire ſtone.

Purbeck ſtone is a hard greyiſh ſtone, and ſerves chiefly for paving, coping of walls, and for all ſuch uſes where ſtrength is required, as being the moſt hard and durable ſtone, after the *Plimouth* marble, we know of; it is found upon the coaſt of *Suſſex* near the ſea ſide.

Rag ſtone is that which is commonly uſed in paving, and is of a blueiſh kind: but there is a ſtone called *Kentiſh* rags that are very uſeful in building, they ſplit very eaſily and yet are very hard; a great quantity of this ſtone has been uſed in *Weſtminſter* bridge; they are brought down the river *Medway* from ſome place near *Maidſtone*.

Alabaſter is a clear whitiſh ſtone not unlike marble; it is very plenty in ſome parts of *Italy*, but there is none to be found in *England*; excepting in ſome parts of *Scotland*, where it is ſaid to be very plenty, and much uſed for making lime, which is exceeding good.

Free ſtone is that which comes from *Portland*, an iſland near *Dorſetſhire*, and is commonly called *Portland* ſtone: this ſtone is chiefly uſed in and about *London*, in all great or ſmall buildings; it is a fine whitiſh ſtone, without any veins, but very dear; for it coſts about ninepence a cubic foot upon the ſpot, and 16 cubic feet weigh a ton: this ſtone is very ſoft when it comes out of the quarry, works very eaſily and becomes very hard in time; the piers and arches at *Weſtminſter* bridge are built with it. There is likewiſe a quarry of free ſtone at *Bath*, of which moſt houſes are built there: it has a fine whitiſh colour, but I am informed that is not durable, and therefore is not ſo fit for great heavy buildings as the *Portland* ſtone.

When the ſtones are drawn out of quarries and only roughly ſquared, they are called aſhler, but when they are ſquared and finiſhed, receive other names from the ſituation they are placed. It may be obſerved that when ſtones are laid in the ſame poſition as they are found in quarries, that is flat or horizontally, they will make better work than if they are laid any other ways: and they will cement ſtronger together; this the workmen will not always obſerve, unleſs care be taken to make them do ſo.

SECT II.

Of BRICKS.

BRICKS are made here of various kinds and colours; and have various names, as clinkers, ſamel or ſandal, ſtatute bricks, didoron, tetradoron, pentadoron, compaſs, concave, featheredge, triangular, cogging, place and ſtock bricks.

The compaſs bricks are of a circular form, their uſe is for ſteening of walls; the concave or hollow bricks are like common bricks on one ſide, but on the other they have a cavity, ſemi-cilindrical, about three quarters of an inch deep, and half an inch broad, ſo that if two of theſe bricks are placed with their hollow together, they are like a pipe of an inch and a half bore; they are uſually a foot long, 4 ½ inches broad, and 2 ¼ thick, they are generally laid in clay, and ſerve inſtead of leaden or wooden pipes to conduct water, as being much cheaper than any other materials.

Cogging bricks, are moſtly uſed in *Suſſex*, to make their work toothing or indented work under the copeing of walls built of great bricks: they are about ten inches long, 4 broad, and 2 ¼ thick. Copeing bricks are about 12 inches ſquare, and 4 thick, flat underneath, and one third above is ſemi-circular, and the two ends flat.

Clinkers are nothing elſe than thoſe common bricks that lie in the middle of the kiln or clamps, where they are ſo much burnt, that they are as if it were glazed all over; theſe bricks are always dearer than the reſt of the ſame make, and are chiefly uſed in foundations, and facing the walls, eſpecially where any water comes near the wall, as being the moſt durable.

Didoron were a ſort of bricks uſed by the antients of a foot and a half long, and a foot broad, but nearly as thin as common tiles. Great bricks are 12 inches long, 6 broad, and three thick; they are generally uſed in fence walls, made with pilaſters or buttreſſes, and in copeing. This manner of building walls ſaves great expences, and they will ſtand as long as if they were every where of the ſame thickneſs.

Paving bricks are made of various ſizes and forms, from 6, 8, 10, and 12 inches ſquare, and an inch and a quarter more or leſs thick; thoſe in the form of an hexagon look beſt; they ought to be of good earth and thoroughly well burnt, otherwiſe they will moulder away in a ſhort time.

Place bricks differ not in form, but in the manner of making them, being of the common dimenſions, *viz.* 9 inches long, 4 ½ broad, and 2 ¼ thick, as the ſtatute bricks; they weigh nearly five pounds each, though ſome will weigh 5 ½; this depends on the quality of the earth they are made of, and on their being well burnt: A cubic yard contains about 460 bricks nearly; which at five pounds, makes two tons and 300 weight *per* cubic yard.

There are two ways of burning bricks, in kilns and in clamps; a kiln is a large hole in the form of a reverſed fruſtum of a cone, that is with the leſſer baſe below, built with brick, and a ſufficient quantity of earth about it, to keep the heat in as long as is poſſible; the bricks are not laid cloſe together, but leaving ſmall diſtances between them, that the heat may paſs between; and the fire is made underneath, where an opening is left for that purpoſe: This way of burning bricks is eſteemed the beſt, becauſe the figure of the kiln, and the wall about it, are ſuch that all the bricks within are nearly burnt of the ſame hardneſs; but where there is a great quantity required, it takes up much time to burn them, for which reaſon they uſe clamps in this caſe; which is nothing elſe than a great ſquare or oblong pile of bricks laid ſo as to leave a ſmall interval between them, for the heat to paſs to the external parts; about this pile earth and bricks, which are not ſufficiently burnt, are laid to keep the heat in. About *London*, where they have plenty of cinders, they throw ſome between each row, which helps to burn them much ſooner, and with leſs fire than is otherwiſe required.

An ingenious brickmaker told me, that he could burn bricks as well in clamps as in kilns, provided he did it with wood; but the beſt way of burning bricks for a fortreſs, is to uſe both kilns and clamps at the ſame time, in order to have a ſufficient ſtock of well burnt bricks for the facings and foundations of of the walls and other buildings.

A bricklayer with his labourer will lay 1000 bricks with eaſe in a day, when the wall is but a brick and a half or two bricks thick, and therefore he may lay more in thick walls; and ſince a cubic yard contains 460 bricks, he will lay above two cubic yards in a day, and from hence it may be computed how many bricklayers are required to finiſh a certain piece of work in any given time.

An ingenious man, uſed much in brickwork, propoſed a larger kind of bricks for walls to be built in water, or in a fortification; their ſize were to be 18 inches long, 9 broad, and 4.5 thick, and he affirmed to have made ſuch bricks in *Scotland*. But a *London* brickmaker objected againſt them; that they could not be managed before they are burnt, as being too heavy, and it would be a difficult matter to burn them quite through: whether this objection is well grounded or not, I ſhall leave to thoſe who are well verſed in this buſineſs.

It is certain, that if ſuch bricks could be made, they would be very uſeful in great works, both upon dry ground and in water, for in the latter caſe, they would not require ſo much terraſs to lay them in as the ſmall one, which being very dear, would ſave great expences. The *Greeks* and *Romans* uſed bricks of 3 feet long and a foot broad, in their public buildings, but then they were very thin, that is, about an inch and a half thick, as may be ſeen in ſome old buildings, ſuch as the old caſtle at *Canterbury*; but at preſent brickmakers diſapprove all other ſizes but thoſe they are uſed to, not caring to go out of their own road.

An engineer told me, that he joined ſeveral bricks together with ſtrong mortar to compoſe as it were large ſtones, with which he formed the angles of the fortreſs: this muſt certainly make the walls ſtronger than by laying the bricks ſingly one after another in the uſual way.

It is my opinion, that bricks might be made of the ſize of four common ones joined together, that is 18 inches long, 9 broad, and 2 ¼ thick: For as they are no thicker than the uſual ones, they would require very little more burning, and ſeveral of theſe being cemented together, might ſerve inſtead of ſtone to ſtrengthen the wall in thoſe places where it is moſtly wanted; I propoſe this only in ſuch places where no ſtone is to be had, becauſe it is very certain that wherever that can be had, it is much better than bricks.

It has been objected, that bricks will not laſt in ſalt water; but by conſulting Mr. *Bratte*, the maſter bricklayer of the ordnance, a man of great practice, he told me, that if the bricks were well burnt, ſuch as clinkers, and made of the ſame clay without any mixture, they would laſt as long in ſalt water as any ſtone whatſoever; as a proof of which he had built the wharfs at *Woolwich* and *Chatham*, and beſides, in ſome other places they were uſed, and without the leaſt appearance of any decay, though a good many years ago.

A friend of mine told me, that he had ſeen piers of an harbour at *Arles* in the ſouthern parts of *France*, entirely built of bricks, and of ſuch an age, that the ſea has quite left the harbour which is now upon dry land.

There is a kind of bricks called grey ſtock, which make a very beautiful appearance in buildings, and are chiefly uſed in and about *London*, in all front walls, which are expoſed to view: The Duke of *Norfolk's* houſe in St. *James's* ſquare is built of a particular ſort, the moſt beautiful that ever were ſeen, but they are very dear; theſe bricks are made in the country, and of a compoſition which I could not learn, it being a kind of myſtery known but by a few workmen. Mr. *Bratte*, our maſter bricklayer, ſhewed me ſome bricks of a pale whitiſh colour, the fineſt ſort I ever ſaw; they appeared to me, as if they were made of red clay mixed with chalk, are very hard and ſound like a hard ſtone; the inſides of the pieces are very ſmooth, without any cavities: if theſe bricks were better known, I think they would be preferred to any other ſort that I have yet ſeen.

The beſt way of making bricks, is to dig the earth before winter, and to let it be expoſed to the weather during the winter, which mellows the earth very much, and ſaves a great deal of labour in preparing it, and the bricks ſhould be made in *April*, *May*, *June*, or *July*; for after that ſeaſon the weather grows damp, and then they will not burn ſo well; and it is pretended by able bricklayers, that bricks ſhould be two years old before they are laid, in order to make good work, and no brickwork ſhould be made after the month of *Auguſt*; becauſe the mortar has not time to harden before the damp weather comes in; by which it peals off, and the works require new pointing the very next ſummer, as I have been myſelf an eye-witneſs to ſuch works.

As bricks are nothing elſe than artificial ſtones to ſupply the want of real ones, there is no doubt but their durableneſs depends on the goodneſs of the materials,

rials, well mixt, prepared, and well burnt; and therefore, an engineer that propoſes to make good work, muſt be very careful in his choice; but the beſt way to prevent any impoſition, is to have the bricks made near the place where the fortr
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would not calcine them; for which reaſon, I am of opinion, that they make no lime, and thoſe who pretend they do, have it only from hearſay, without any other proof.

It is my opinion, that all ſtones that have any metallic particles in them, and thoſe that will vitrify, will never calcine, at leaſt, I always found it ſo; but leſt I ſhould be miſtaken, I leave it to the chemiſts, and thoſe that have an opportunity of making more experiments than I, to decide it.

Different counties in *England* produce different kinds of lime-ſtones; in *Kent*, where there are a great many chalk-pits, they make their lime of chalk, and the greateſt part of the lime uſed in and about *London* comes from thence, chiefly becauſe of the conveniency to bring it by water, which makes it much cheaper than any other that is brought by land: But this ſort is the very worſt that can be made; it is true, it may ſerve very well for whitewaſhing, and other things in the inſide of a building; but as moſt buildings are upon leaſes, people are not ſo nice about the ſtrength and goodneſs of the work; provided it laſts as long as they want it, it is ſufficient.

I have been informed that about eight miles from *Portſmouth*, is a chalky rock, pretty hard, that makes very good lime, and has been much uſed in the building the fortification of that place: although the *Purbeck* ſtone which is not a great way of, and the fragments of *Portland* ſtone, make exceeding good lime: I ſuppoſe the former lime is uſed not becauſe it is better, but cheaper than the other, which is a very bad reaſon, ſince all public works, which are of great importance, ought to be made as ſtrong and durable as is poſſible; for what is ſaved by cheapneſs of the materials, is loſt by the ſhort ſtanding of the works,

The beſt lime in any part of *England*, is that which is made of the marble, found near about *Plymouth*, and is very much uſed in all the country thereabout:

the *Romans* and *Italians* made uſe of no other lime than that of marble, in all their great and publick buildings, it being the very beſt that can be made, and of conſequence, makes the buildings more laſting than any other.

Moſt builders in this country do not ſtand ſo much upon a good reputation, as to make moſt money of their works; and few gentlemen enter into the knowledge of building; ſo that the works are generally badly executed; provided the outſide of walls appears well, it is no matter how the reſt is: What ſpoils the method of making ſtrong and good walls is, that moſt houſes in and about *London* are built upon leaſes, ſo that if they but ſtand the number of years propoſed, the proprietors are ſatisfied, and give themſelves no further trouble; this cauſes the workmen to make their work in a ſlight and expeditious manner.

I am informed, that in moſt parts of *Scotland* there are exceeding good lime ſtones, and in great quantity, in ſuch a manner as to uſe the ſame ſtone for lime as they build with; in ſome parts they have alabaſter, which makes as good lime as marble. In *Ireland*, eſpecially about *Dublin*, lime ſtones are likewiſe ſo plenty as to build with, which makes the beſt work; becauſe the mortar unites better with the ſtone, than if the parts were diſſimilar.

An engineer employed in any part of the country, ought to examine all the different ſtones to be had thereabouts, in order to find that which makes the beſt lime, and he ought not to chuſe any becauſe it is the cheapeſt, which can ſcarcely be excuſed in private buildings, but ſuch as will make the beſt work; and ſince lime is the very ſoul of good maſonry, it cannot be too good; but if it ſhould ſo happen that all the lime in the country is very bad, he ſhould get as much from other parts that is good, as to ſerve for the facings of the wall, for fourteen or fifteen inches deep; the reſt may be done with the cheapeſt ſort.

Lime is burnt in kilns much like thoſe of bricks; and the ſtones muſt be broke into pieces the bigneſs of a fiſt, and more eſpecially ſo when the ſtone is very hard; but when they are ſoft, ſuch as chalk, it requires not ſo much precaution: Care muſt be taken to burn it every where alike, and thoroughly; otherwiſe, thoſe parts which are not well burnt, will not ſlaken with the reſt, and when the mortar is employed, will diſſolve, and diſunite the wall wherever there is any of them.

There is likewiſe lime made of all ſorts of ſhells of ſea-fiſh, which is eſteemed to be exceeding good, becauſe it dries and hardens in a ſhort time, for which reaſon it is mixt with *Dutch* terraſs, and uſed in all aquatic works, and as it is much cheaper than terraſs, it ſaves great expences.

It muſt be obſerved, that thoſe ſtones taken out of quarries which are damp, make better lime than thoſe found above ground and are dry; it has likewiſe been found, that the dryeſt part of a rock, and which is expoſed to the ſun, will make a different lime from that made of the inner part, which is damp and not expoſed to the ſun: Therefore an able engineer ſhould not only try the outward parts of a rock, or a quarry, but likewiſe thoſe parts which are not expoſed to the ſun and weather; otherwiſe he may poſſibly reject the beſt part as uſeleſs.

SECT. IV.

Of SAND, TERRASS *and* POZOLAN.

ALTHOUGH there appears very little difference in ſand, yet there is ſome which being mixt with lime makes much better mortar than others: In common buildings, they always uſe that which is neareſt at hand, and in *London* they beat the rubbiſh of demoliſhed buildings, and uſe it as ſand; but in works of conſequence, ſuch as thoſe of a fortreſs, ſuch a practice ought to be rejected; the beſt materials ſhould be uſed in order to make durable work, for which reaſon greater precautions muſt be taken; and it is for the ſake of thoſe works we intend the following obſervations.

The beſt ſand for good mortar is that whoſe grain is not too ſmall, which is clear and free from earthy particles; for the ſmall grained ſand has been found not ſo good, as being too fine to form a ſolid body when mixt with lime.

The manner of knowing whether ſand is free from earthy particles, is to take ſome and rub it in your hands, and if it makes them dirty, it is a ſure ſign that it is not pure, but if it be gritty and leaves no dirt behind it is very good. If it ſhould happen that no good ſand is to be found near the place where it is wanted, the beſt way will be to waſh as much as is required to make ſtrong mortar, for facing, and pointing arches, and other ſuch like works; that is, you put a good quantity into a tub, and fill it with water, then ſtir it well with a ſtick, and let the water run off; pour clean water in again, ſtir it and let it run out; this being continued till the water is pretty clear, your ſand will be clean.

Sand found in rivers is eſteemed the beſt, becauſe it is of a pretty coarſe grain, and moſtly free from mud; others will have it that ſand out of the ſea or ſalt water is likewiſe very good; but as for my part, I would not chuſe to uſe it, where good work is to be made, becauſe ſalt, if I am not miſtaken, is a bad ingredient for mortar; this will be explained hereafter.

It has been found by experience, that ſand ſhould be uſed freſh, and before it has been too much expoſed to the air; for it is ſaid, that dry ſand never makes good mortar; although mixt with a ſufficient quantity of good lime; and therefore when a large quantity is brought to the place where it is wanted, it ſhould be covered ſo as the ſun may not ſhine upon it.

Inſtead of ſand mixt with lime to make mortar, ſeveral other things are uſed, ſuch as cinders, tiles, ſcalings of iron out of forges; but theſe ingredients muſt be well beat, ſo as to make a fine powder of them. I made ſeveral experiments with theſe materials, and found when they were well mixt with lime made excellent mortar; ſome of which being put in the joints of walls in the month of *December*, the weather being very damp, and others kept in a warm room, made up in ſmall balls, that which was expoſed to the air dried as ſoon, and grew as hard, as the other: Neither could I perceive any difference between the mortars made of theſe different ingredients, for they grew all equally hard nearly at the ſame time, although ſome pretend, that the ſcalings of iron makes the ſtrongeſt mortar.

I have been told by a gentleman, that he has ſeen mortar compoſed of ſcalings of iron, and common lime, to be uſed in ciſterns, and that it grew ſo hard that the water could never penetrate it; but it muſt be obſerved, that mortar of this kind is worked with very little water, in ſuch a manner as to become like a ſtrong clay.

There are ſeveral other kinds of powder uſed in mortar inſtead of ſand, eſpecially for ciſterns and aquatic works; there is a ſort which is called pozolana, from the name of the place it comes from, which is in the kingdom of *Naples*; this powder is of a reddiſh colour, and when mixt with lime grows preſently hard and remains ſo although in water.

Another ſort made of a ſoft rock ſtone, found near *Collen* upon the lower part of the *Rhine*; it is burnt like lime, and afterwards reduced to powder by means of mills; from thence it is brought to *Holland* in great quantities, where it has acquired the name of *Dutch* terraſs; it is of a greyiſh colour when it is not mixt, which is very ſeldom the caſe; becauſe it is very dear, and abſolutely neceſſary in all aquatic works, and ſo they make as much of it as they can.

We have forgot to mention before, that lime ſhould be burnt with coals and never with wood; the reaſon given for it is, that the coals being ſtrongly inpregnated with ſulphureous particles, which mixing with the lime makes it more glutinous; and it has been found that the mixture of the cinders and the ſmall particles of lime, found in the lime kiln, being reduced to a powder and uſed inſtead of ſand, compoſes a mortar as ſtrong for aquatic works as *Dutch* terraſs. The reaſon of this appears to be owing to the particles of lime being mixt with the cinders and unſlakened, when they are mixt with lime they ſlaken and dry up the watery parts of the lime, and leave no more moiſture in it than what is ſufficient to lay hold on the bricks or ſtones, and compoſe as it were one ſolid body.

I have been informed, that in ſome parts of *England*, which is *Dorſetſhire*, if I am not miſtaken, is found a ſoft ſtone, much like that of *Dutch* terraſs, and that it might ſerve full as well in aquatic works; if this be true, I am ſurprized that it is not better known, ſince it would enable us to make theſe kind of works of our own materials, and much cheaper, than to buy them from the *Dutch*, who often mix it with other things, to get the more by it. As for my part, I do not doubt, that if there was a proper enquiry made by ſuch as have it in their power, but they might not only find ſuch ſort of lime ſtone as that of which the terraſs is made of, but likewiſe the ſort which makes plaſter of *Paris*.

N. B. There is at preſent ſuch terraſs made here, and ſold for eighteen pence a buſhel, whereas the *Dutch* coſts two ſhillings, and is not better.

SECT.

SECT. V.

How to prepare and make MORTAR.

THE manner of making mortar is quite different in different countries, and even in the ſame country by different builders; the common way in and about *London*, is, to lay the lime ſtones upon a heap, and cover it with as much ſand as is thought requiſite for making the mortar; then they fling ſome water on it, ſo as the lime may ſlaken gradually and mix it at the ſame time, which they continue till the lime is ſlakened; when this is done, they paſs it through a ſcreen the next day, in order to ſeparate it from the ſmall ſtones, which have not been ſufficiently burnt to ſlaken ſo ſoon; after this they mix it and beat it well; and uſe it immediately without any further ceremony.

But our engineers uſe greater precautions; for they mix and beat it every 24 hours for a week together, and then let it lie for a week more, and when they uſe it, beat and mix it again: by this means it will make good mortar although the lime is but indifferent, provided, there is not too much ſand put into it.

The proportion moſt commonly uſed in the mixing of lime and ſand is, to a buſhel of lime a buſhel and a half of ſand; that is two of lime and three of ſand; this however is no general rule, for ſome lime is fatter or more glutinous than others, and therefore will bear a greater quantity of ſand. The common mortar in and about *London* has more ſand in it than according to the proportion above: for provided there is juſt lime enough to keep the ſand together, the workmen are ſatisfied: and they make large joints, becauſe this kind of mortar being cheaper than bricks, they get ſo much more by their work, than if they made the joints ſmaller; but if they are obliged to make good mortar, they make ſmaller joints, becauſe the mortar coſts them more than bricks.

The *French* make their mortar in a quite different manner; for they dig a ſquare hole in the ground, a foot or 18 inches deep, and large in proportion to the quantity of lime they intend to ſlaken; they floor the bottom with boards; then they throw in lime firſt 6 or 8 inches deep, and pour in as much water as will juſt cover the lime; which they ſtir till the lime ſtones are diſſolved; when this is done they make their mortar in a few days after: this is the common practice, but in works of conſequence, they cover it with one third of ſand and let it lie for a twelve month. It is pretended that the ancients ſlakened their lime many years before they uſed it; and there are ſome who ſay that freſh mortar is better than old: but in my opinion the nature of the lime ſhould be conſulted; for when lime is very ſtrong, by letting it lie too long it will grow hard and unfit for uſe, as it happened at *Metz*, as Mr. *Belidor* ſays, where they let it lie a twelve month, in which time it became as hard as ſtone: but when lime is bad, I take it, the longer it lies the better it becomes.

Two things are to be obſerved, in order to make good mortar, which are, that no unſlackened particles of lime remain, and not putting too much water in it when it is prepared: therefore if lime is kept till every part is ſlackened it will be ſufficient. It muſt likewiſe be obſerved, that burnt lime ſhould not be kept too long before it is ſlakened, becauſe it evaporates and the air makes it loſe its property; but when lime is once ſlakened and well covered with ſand, as likewiſe under ſhelter from the ſun and rain, it will keep as long as you pleaſe, provided it does not grow too hard.

The water that is uſed in the ſlaking of lime, requires likewiſe to be conſidered; for if it be dirty and full of mud, ſuch as is gathered in the ſtreets, as they do at *London*, it will ſpoil the mortar; it is imagined that all kind of clear freſh water is good; but I believe the ſofter the water is, the better: ſome pretend, that ſalt water out of the ſea may be uſed; but for my part I think it muſt diminiſh the goodneſs of the mortar very much: for it is well known that ſalt gives way and becomes fluid in damp weather, and therefore in winter, the mortar which is impregnated with ſalt muſt neceſſarily become ſoft, whereby it loſes the property of binding bodies together in bad weather, when it ſhould have moſt.

Mortar that is to be uſed directly, which ought never to be done but in caſes of great neceſſity, ſhould be ſlakned by covering it with ſand on a platform, and the water thrown over it little by little, ſo as to diſſolve it gradually, and then paſſing it through the ſcreen to free it from the ſmall ſtones not diſſolved; this being done, it ſhould be well beat and worked once a day for a week, and let it lie for another, and when it is uſed, to work is well again; and no water ſhould be uſed but the firſt time: but when mortar can be made betimes, it may be made in the manner mentioned above and let it lie for about ſix months, which will be ſufficient to diſſolve all the parts of the lime that is burnt, and the reſt which are not burnt will not affect the work; although thoſe that are found may be thrown away.

The mortar made for ceilings is different from that we have been ſpeaking of; it is made of ox or cows hair well mixt and tempered with lime and water, without any ſand: the common method of making this mortar is, one buſhel of hair to ſix buſhels of lime; the hairs ſerve to keep the lime or mortar from cracking, and to bind and hold it faſt together.

Mortar made of terras, pozolana, tile duſt, or cinders, is mixt and prepared in the ſame manner as common mortar; only theſe ingredients are mixt with lime inſtead of ſand in a due proportion, which is about half and half: as this mortar is deſigned for aquatic buildings, the reader may eaſily imagine that the lime uſed in it ought to be the very beſt that can be had: for which reaſon, lime made of ſhells or of marble is what ſhould be had if poſſible, but in ſuch works which are ſometimes dry and at others wet, inſtead of terraſs, which is very dear, tile duſt or cinder duſt may be uſed, and is eſteemed to be the beſt mortar for ſuch work; for it has been found that terraſs mortar is not ſo good where the work is expoſed to the air.

In fortifications, docks, or piers of harbours, I would lay all the parts of the works under water with terraſs mortar, and the reſt of the facings, both within and without, with cinder or tile duſt mortar, for about two feet deep; for if this was done, the walls would not require to be pointed and repaired as they commonly do: cellars, and all kinds of arches or vaults, under and above ground ſhould likewiſe be done with this mortar: and the cinders out of lime kilns mixt with the particles of lime ſtone, is, in my opinion, ſtill preferable, for the reaſons given in ſection III. As to ciſterns, they require terraſs mortar as well as all the works which are conſtantly under water.

The ſtrength or goodneſs of mortar does not only depend on that of the materials of which it is made, but likewiſe on the manner of preparing it: for the workmen put generally much water in it to make it liquid, in order to ſave labour in mixing it; if this be done, the mortar will never be good for any thing: but if little or no water is uſed after it is ſlakened, and well beat, and mixt till it becomes ſoft, and this be repeated ſeveral times till it becomes glutinous, you may depend upon it, that the mortar is good.

A very able perſon, who has been employed a great while in the works of fortification, told me, that he wets his mortar very ſparingly, but beats it well every day for a week, and then lets it lie for a week or a fortnight before he uſes it, and has it well beat over again: this method is undoubtedly very good, and ought to be uſed in all the works of fortifications, ſince they are a great charge to the nation, and therefore whoever has the direction of them ought in a manner to be anſwerable for their goodneſs.

A contrary practice is followed by ſome others, who have the direction of works; for I have ſeen, after works have been done, the mortar crumble off like ſand, and when examined, found the lime in lumps, and not half mixt with the ſand; what can be expected from ſuch work, I leave the reader to judge. Others pique themſelves upon making the work look regular; and will have every courſe of bricks to be three inches high: and as the bricks are but two inches and a quarter thick, the joints muſt be three quarters, from whence the goodneſs of the work may be judged: inſtead of making the joints ſo large, I would oblige the bricklayers to make them only a quarter of an inch thick, which is ſufficient.

Another obſervation is to be made, which is, that in all walls that have a ſlope, the courſes of brick ought to be perpendicular to the ſlope, and not on the ſame level, as is cuſtomary; and this for two reaſons; firſt, all ſtones being cut ſquare cauſe leaſt waſte, and is eaſier to the workmen; and when bricks are uſed, the joints are equally thick throughout, whereas, when the courſes are on the ſame level they raiſe the bricks on the outſide, ſo as to make the ſlope, which makes them wider there than within; and when the mortar is not very good, the walls require pointing very often: another inconvenience ariſes, that the outſide of the courſe being perpendicular to the ſlope a brick length, and the reſt lie horizontally, by which they make an angle or bending, ſo that the bricks of the ſame courſe can never bind together, and the outſide of the wall is no more than a ſhell the depth of a brick, ſeparated from the reſt of the work.

SECT. VI.

Of PLASTER.

PLASTER is different from common lime, in that it compoſes a ſolid body by itſelf, without mixing either ſand or any other ingredient, as is done in lime.

It is made of a bluiſh ſoft ſtone, taken out of quarries, which generally are at the ſide of a hill, much like the ſtone of which *Dutch* terraſs is made: This ſtone is burnt in the ſame manner as lime, and when cold, beat into a very fine powder, or duſt; and when it is to be uſed, about a buſhel is put into a tub and water poured in, till it becomes liquid; then it is well ſtirred with a ſtick, and uſed immediately; for in leſs than a quarter of an hour it becomes hard, and good for nothing: another of its properties, is, that it will not bear mixing a ſecond time, as lime will do.

Although plaſter is to be found in moſt countries, yet nobody I know, has given a method to diſtinguiſh it from lime ſtone: I am apt to think, that it may poſſibly be the ſame ſort of ſtone as that found near *Collen*, of which the *Dutch* terraſs is made; for if it is not the ſame ſort, it comes very near to it; for it dries very quick, and makes a very hard body: it is ſaid not to remain hard in water, but I never heard that it was tried with mixing it with lime; for which reaſon, I will not affirm it to be the ſame as terraſs.

That which is found in a hill near *Paris*, is eſteemed the fineſt, and brought to *England* chiefly to make buſto's, and to take off medals, as well as all kind of ſtatuary works; but there it is uſed in flooring, and to line the inſide of ſtone walls, inſtead of common mortar. But the plaſter found in this country, being of a coarſer ſort, is chiefly uſed to make floors for gentlemens houſes, and for granaries to keep corn in.

The only way to know the ſtone, is to burn it in a fire, and reduce it to a fine powder; then if it grows hard immediately after it has been mixt with water, you are certain that it is plaſter; although the ſtone is of a blue greyiſh colour at firſt, yet it becomes very white by burning, and when mixed with water, it does not ferment or grow hot like lime.

Having thus given the quality and manner of preparing the chief materials uſed in works of a fortification, in the preceding ſections, as far as we poſſible could from our own obſervations, and what we could gather from other authors; to which, if the young engineer will join his own obſervations with thoſe of his ſuperiors, under whom he is employed, eſpecially to thoſe of able workmen, I do not queſtion, but he will be able, not only to judge whether works are well executed, either in the whole or in parts, but likewiſe know how to proceed whenever he ſhall be employed as the chief director over ſuch works, for which reaſon, we ſhall proceed to what remains to be ſaid of this ſubject.

PART III.

Containing the manner of tracing a Fortreſs on the Ground, to make an Eſtimate, and to execute the Works.

SECT I.

Shewing the USEFULNESS *and* NECESSITY *of building* FORTRESSES.

THE neceſſity of building fortreſſes in all ſtates whatſoever, appears from this innate principle of ſelf preſervation; for a powerful nation has always powerful enemies; ſo that by the loſs of a battle, the whole country is in danger, if the remainder of the routed army has no place of ſafety to retire into, where they may rally and receive ſuccours, either from their allies, or new-raiſed troops from that part of the country, which the enemy is not yet maſter of.

It has often happened, that after an army has been defeated, it has received ſuch ſuccours in a place of ſafety, as not only to be enabled to ſuccour their own country, but likewiſe drive the victorious army out of the field with loſs: There are many ſuch examples to be found, both in antient and modern hiſtories: Whereas, if an enemy gets once the victory in a country that has no fortreſſes, he is at that inſtant maſter of the whole ſtate.

An example of this kind has happened here in *England*; for had there been ſome good fortified places, when *William* the conquerer entered the country, it would not have been loſt by gaining of one battle; and had the town of *Genoa* been fortified in the laſt war, the *Auſtrians* could not have taken it at once, and been maſters of the whole ſtate, as they did; in ſhort, were it not for the many fortified places in *Flanders*, the *Auſtrian* dominions in that country would have been long ago loſt.

In ſmall ſtates and republics, they are no leſs neceſſary than in great kingdoms, in order to reſiſt a powerful enemy, till ſuch time that their allies can come to their aſſiſtance: To this it may be objected, that fortified places in a free ſtate, may be a means to enſlave it by ſome ambitious and powerful man, aſſiſted by a neighbouring prince; but as no ſuch examples are recorded in hiſtory, as far as I know, and the contrary is evident, by the ſtates of *Holland*, who have many fortified places, and yet have preſerved their liberty, ſince their firſt ſeparation from the *Spaniards*, it is evident, that this objection has no foundation.

Maritime powers, and thoſe who inhabit iſlands, ſuch as *England*, *Sardinia*, *Sicily*, *&c.* require no leſs fortified places; for as an enemy may invade them by a ſurprize, and though his naval force be leſs, yet when he once gets a footing, may either conquer or deſtroy the country. Beſides, their trade, on which iſlanders chiefly depend, would become very precarious, without having ſome ſtrong place or other to ſecure their effects in, which otherwiſe might be ſurprized and carried of, before an army can arrive to defend them. Many other arguments might be alledged to prove the uſefulneſs of fortified places, were it not that all the world is convinced of it at preſent, and therefore it would be needleſs to ſay any more about it.

SECT. II.

Of their SITUATIONS.

THE ſituation of a fortreſs depends chiefly on the reaſons for which they are built; for if they are to promote or protect trade, they muſt be placed near the ſea, lakes, navigable rivers, or chanels; if they are deſigned to guard a paſs or inlet into a country, they are placed on hills or high ground, that from thence they may enfilade and defend that paſs, and ſo as not to be commanded by any other adjacent hill; or near the paſſage of a large river; and if they are to ſecure a country from an invaſion, they muſt be ſituated in ſuch a manner, that the enemy muſt attack them before he can advance any farther; and in caſe he ſhould paſs by and leave them behind, they may cut off his communication with his own country, whereby his convoys may become precarious and difficult; and therefore muſt either not advance farther or elſe beſiege them.

In iſlands, the beſt ſituations are upon the coaſts, and in ſuch places, where an enemy may eaſily land, and where the garriſon has a ſafe communication with ſome inland town, to receive ſuccours and ſubſiſtance in caſe of an attack; or if there are any great rivers, that run into the ſea, and where ſhips may come up into the country, there ſhould always be one or more fortreſſes built near them, in ſuch places, as may prevent the ſhips from paſſing by, without ſuffering greatly from the cannon placed there, and where the approach is very dangerous.

In an iſland of no very great extent, whoſe coaſt is of an eaſy acceſs, in moſt parts, and where it is impoſſible to fortify every one; the beſt ſituation for a fortreſs is the middle of the iſland upon a riſing ground;

becauſe troops may beſt be ſent from thence to any part, to oppoſe the landing of an enemy; but this fortreſs ſhould be pretty large, that in time of need, the inhabitants of the country may retire into it with their cattle, and other moſt valuable effects, and help to defend the place, till the enemy is obliged to retire, either for want of proviſion, or having no hopes to get maſters of the place.

But if the iſland is conſiderable, it is not ſufficient to build fortreſſes near the moſt convenient landing places, but there ſhould likewiſe ſome be built in the paſſes, to prevent an enemy from entring farther into the country, in caſe he ſhould land, notwithſtanding the forts on the coaſt; or at leaſt to ſtop and protract time, ſo as the country may riſe and come to oppoſe him.

In ſmall ſtates, that lie in an open country, which cannot afford the expences of building many fortreſſes, and are not able to provide them when built with ſufficient garriſons and other neceſſaries for their defence, or thoſe whoſe chief dependance conſiſts in the protection of their allies; the beſt way is to fortify their capital, which being made ſpacious, may ſerve as a retreat to the inhabitants in time of danger, with their wealth and cattle, till the ſuccours of their allies arrive.

If a fortreſs is built near a river, lake, or ſea, it muſt be conſidered whether it ſhould ſtand quite cloſe to the water ſide, or at ſome diſtance, ſo as the works may not be battered by the ſhips; whether an enemy may eaſily land thereabouts, and attack it by land; whether the ſhips may come cloſe, or the water is ſhallow, when the water is ſo deep that ſhips can come up cloſe to the walls, the parapets muſt be made high, and thoſe that can be ſeen from the main top, ſhould be covered above with canvaſs, planks, or with any thing elſe in time of a ſiege, to cover the troops behind them.

When a fort lies ſo near the water, that it may be battered from the ſhips, it is in danger of being ſoon deſtroyed by the ſuperiority of their fire; on the contrary, when the water is ſo ſhallow, that the ſhips cannot come near enough to batter in breach; care muſt be taken that the enemy may not land in their boats, and ſtorm it by land; to obſtruct which, redoubts or batteries muſt be built, to reſiſt both in front and in flank; and if they can land any where beyond the reach of cannon, theſe redoubts or batteries muſt be fortified all round with a wall and good ditch, that they may not be ſurprized in the rear; as we did at *Cape Briton*; where the large battery fronting the entrance of the harbour, was ſurprized, and the guns turned againſt the town, by which it was obliged to ſurrender; this would not have happened, if the precaution mentioned above had been uſed.

In a place where there is a harbour, ſome parts or other of the fortreſs ſhould command it if poſſible; for though redoubts and batteries are made to defend its' entrance, yet if the enemy finds means to deſtroy ſome, and paſſes by others, the harbour lies open for the ſhips to come in, without any farther obſtacle: and as theſe defences are at ſome diſtance from the fortreſs, they are always taken either by ſtratagem or main force; as being ſeparate from the garriſon, and are not eaſily relieved. But if part of the fortreſs commands the harbour, the ſhips are never ſecure in it till the place is taken, which is all that can be expected.

It is true, that the entrance ſhould not be neglected; for wherever there is a point of land that commands the approach of an enemy, it ſhould be carefully ſecured by ſome work or other; and as it often happens that ſmall rocky iſlands lie in the entrance, which, when properly fortified, are very advantageous in the defence of it: Nothing conduces ſo much to the ſafety of a place, ſituated near the ſea, or navigable river, as thoſe works which keep the enemies fleet at a diſtance; ſince thereby their main ſtrength is of no uſe to them; and though they ſhould make a deſcent in ſome part or other with a few ſmall pieces, yet theſe may be eaſily repulſed by the garriſon. As theſe kind of ſituations are the moſt uſeful to a trading nation, we have ſo much the longer dwelt upon the method of ſecuring them in the beſt manner poſſible.

When an old fortreſs is to be rebuilt, the engineer ought not rely too much on the capacity of him who had made it firſt; he ſhould conſider whether there is no other ſituation thereabouts, that might be better than the former; whether the old works were properly adapted to the nature of the ground; how much expence will be ſaved by building upon the old foundations; whether it is too big or too little; whether by following partly the old plan, and building the reſt in a different manner, it would not be better than to follow it in all its parts; or whether by chuſing another ſituation, it would not be too expenſive in reſpect to the advantage gained thereby; in ſhort, he ſhould leiſurely, and well conſider every minute circumſtance, in order to form a true idea of the ſituation, the figure of the works, and the conſequences reſulting therefrom, before he determines his choice.

An engineer, who is truly conſcious of the truſt repoſed in him, ought to be extremely cautious in all his undertakings, and well conſider, that he is, or ought to be, anſwerable for all extraordinary and uſeleſs expences, which he cauſes to the nation, either for want of ſkill, or inapplication; and if a nation was rightly ſenſible of the truſt they put upon them, I am perſuaded, that they would be very careful, and well examine thoſe who are deſirous to enter into ſuch employments, before they admit them.

An engineer requires much greater ſkill in arts and ſciences, than is generally imagined; for it is not ſufficient to know how to draw plans, profils, and landſkips,

ſkips; to underſtand a few propoſitions in geometry, or to know how to build a wall or a houſe; on the contrary, he ought to be well grounded in all the moſt uſeful branches of the mathematics, and how to apply them to practice, natural philoſophy, and architecture; have a good notion of all kind of handicraft works; and above all things, to be well verſed in mechanics.

As the variety of nature is infinite, ſo it is impoſſible to deſcribe all the different ſituations, where fortreſſes ſhould be built; it requires the greateſt ſkill and knowledge to fix upon ſuch as may anſwer beſt all the different expectations; and as the building and maintaining them is attended with very great expences, when they do not anſwer the intent for which they are built, they are heavy burthens to a nation, without any conſiderable advantage: for which reaſon an engineer ought ſeriouſly to conſider what he is to do before he begins ſuch an undertaking: It is my humble opinion, that the choice of the ſituation, and the making a ſcheme of a fortreſs ſhould not be intruſted to any ſingle perſon; on the contrary, the expence of ſending five or ſix upon the ſpot, and in concert making a proper choice of the place and works, would be more than ſaved in the execution.

SECT. III.

OBSERVATIONS *relating to the* SITUATIONS *of* PLACES.

IN the former ſection we have treated of ſituations in general, it remains now to obſerve the particulars which are neceſſarily to be known, before the ſcheme or project of a fortreſs is fixed upon. The firſt thing to be conſidered, is to know whether the air is wholeſome; for it would not be for the intereſt of a ſtate, to build a place of that kind without the inhabitants being in a way of increaſing, in order that there may be no occaſion of ſending often a ſupply of people; beſides, a gariſon in ſuch a place, would continually weaken to ſuch a degree, as would make the taking it very eaſy.

This may be known by the colour and ſtrength of thoſe who live there, or near the place; and if it is not inhabited, it may eaſily be known by the ſituation; becauſe if it be ſurrounded by low and marſhy ground, the place is certainly unwholeſome; on the contrary, if the place is a dry ſoil, and produces plenty of wood and graſs, and there are a great number of birds, or wild animals, it is no leſs certain, that the ſituation is wholeſome and fruitful.

The next thing to be conſidered, is to know whether there is a plenty of freſh and wholeſome water, ſufficient for men and beaſts, for without that, no place ought to be fortified, unleſs it may be ſupplied by ſome ſpring not far-of, and which an enemy cannot cut off in time of a ſiege; otherwiſe, it would be impoſſible to defend it for any time. It may be obſerved, that all ſweet waters are not equally wholeſome; for it has been found by experience, that very clear and well-taſted water, has occaſioned particular diſtempers to thoſe that drank it conſtantly. Beſides, as ſome waters will cure diſtempers, why ſhould there be none of contrary qualities? The air of ſome places is eſteemed unwholeſome, when it is rather the water that occaſions the diſtempers. It has been pretended, that the lighteſt waters are the beſt to drink: but Mr. *Cotes*, in his Hydroſtatic lectures, has compared the weights of all the different waters that he could get, even ſome of the river *Ganges*, which is eſteemed the beſt in the world, but could not find any ſenſible difference in their ſpecific gravity; if this be the caſe, its goodneſs cannot depend on its lightneſs, but rather, on ſome quality imbibed from the ſoil, through which it runs, which cannot be diſtinguiſhed by the taſte: Others ſay, with ſome juſtice, that if water be boiled a good while, and let ſtand for a time, till it is quite cold, and when no ſettlement is found at the bottom of the veſſel, it will be wholeſome; this may be better known, by uſing the ſame veſſel for ſome time; and then obſerving whether any ſediments are found; for there may be ſo little at firſt, as not to be perceived, yet in length of time may gather ſo much as to make it appear quite plain.

I have been told by a gentleman of veracity, that very clear and well-taſted water, ſpringing out of a rock in *Ireland*, petrifies every thing on which it falls, in a very ſhort time: Therefore water of that quality can never be wholeſome, either for man or cattle.

Water ſeems to receive its chief quality from the nature of the ſoil, through which it runs, as we have obſerved before; as for inſtance, when it comes out of a rock, or of a gravelly ſoil, it is clear and cold; that which comes out of chalk, is ſoft and milky; and that of a marſhy ſoil, brackiſh; this latter ſort is the worſt of all.

If the inhabitants, or thoſe who live near the place, are ſubject to any particular diſtempers, more than thoſe in others, either the water or the air is unwholeſome; it may eaſily be known, whether the air is good or bad; for if there is any ſtagnated marſhy water adjacent to the place, the heat of the ſun draws up the corrupted particles, which fall in the cool of the night, and infect the air; but if there be no ſuch places near about, the air will be good: It is ſaid, that in bad air, the livers of birds and animals are full of ſpots; but whether this is ſo or not, I cannot ſay.

Next to the water, fuel to make fire is to be conſidered; it muſt therefore be enquired, whether there is wood, coals, or turf to be had near at hand, or may be brought to the place at an eaſy rate, either by land or water: this article is very neceſſary, eſpecially in northern climates; beſides its uſe in preparing victuals, wood ſerves for moſt ſorts of handicraft works; in ſhort, every thing that is neceſſary for the ſubſiſtence and conveniency of a garriſon muſt be conſidered, before the conſtruction of a fortreſs is undertaken, becauſe the expences which attend ſuch works, are always very great; and conſequently, every individual circumſtance ought to be examined and carefully conſidered beforehand.

In the next place, it muſt be obſerved, whether there are materials to be found for the building of the place, either upon the ſpot, or near at hand, ſo as to be tranſported at an eaſy rate; ſuch as timber, ſtone, or brick, lime and ſand, or whether they may be partly had on the ſpot, and partly brought by water; for if the greateſt part is to be tranſported by land from ſome diſtance, the expence will be ſo exceſſive, as the utmoſt importance of the place only can excuſe the building it.

If it be a place near the ſea, or a navigable river, where a harbour is to be made, it muſt be carefully conſidered, on which ſide the fortreſs is to be placed, both in reſpect to the landing of the goods, and to the defence of the harbour, as likewiſe, where the ſhips may come as cloſe to the quay as poſſible.

In a fortreſs built to promote and protect trade, it muſt likewiſe be conſidered, what kind of goods are to be found in or near the place, what might be brought by ſhips from foreign parts, and what might be exported, in exchange for thoſe manufactured there, and where to be carried to market.

It may happen, that in ſome places, ſuch as iſlands and ſome other places, where there are very few things to be had for exportation, yet if the harbour is convenient for ſhips to come in, when diſtreſſed by weather, or the place may ſerve as a magazine to bring and depoſite *European* commodities, to be from thence tranſported by veſſels, to ſome other market; or elſe, freſh water is to be found for ſhips, when no other place is near hand, as is *St. Helena*; ſuch ſituations may be fortified, and become very uſeful.

There are many ſituations in inland countries, which we have not taken notice of here, and yet may be advantageous for building large fortified places, becauſe their uſefulneſs depends on too many circumſtances to be enumerated; therefore we ſhall obſerve in general, never to build a large fortification, excepting near navigable rivers, which may ſerve for conveniency of trade, and to be a ſtrong barrier to a ſtate; or to ſtop a paſs, through which an enemy might enter into the country; for where there is no river, he may paſs by and leave the place behind him; hills that command any of the works, or hollow roads, through which an enemy may approach, ſhould be avoided; and in general, the ground ſhould be level and free from trees, or any other thing, which may favour an approach under cover, for a mile all round.

SECT. IV.

How to make the PLAN *of a* FORTRESS.

WHEN a ſtate has reſolved to build a fortreſs, an engineer is to ſurvey the ſpot of ground, upon which it is to be, very exactly, and to draw the plan of it very diſtinctly, on a large ſcale, which muſt extend at leaſt as far as cannon ſhot beyond any of the outworks, together with ſeveral ſections or profils, ſo as to expreſs the heights of the moſt material inequalities of the ground; if there be any river or ſtanding waters near it, their breadth and length muſt not only be taken and expreſſed in the plan, but likewiſe all the ſoundings, in order to know whether any ſhips or ſmall craft can come there.

If there be any hills or high grounds, or hollow roads near hand, they muſt be carefully expreſſed, both in the plan and ſections; after which the engineer muſt compoſe a memorial, containing an exact and diſtinct account of the nature and ſituation of the ground; if rocky, hilly, marſhy, or even; if there is a river, whether it is navigable or not; or if there be a lake, whether it may be uſeful for navigation, or to ſtrengthen the works; if there is a good foundation to build upon; whether there are ſprings or river water to be had for the uſe of the garriſon; and wood, coals, or turf, for fuel.

If the materials of which it is to be built, are to be had upon the ſpot, or if at any diſtance, how they are to be brought by land or water; the nature and quality of the materials; their prices, and that of the workmanſhip; and above all, whether the works are to be built with ſtone or bricks, where to be had, whether any quarries are near hand, or proper clay to make bricks, and fuel for burning them; where to get the lime and ſand, whether the materials are good, or but indifferent; in ſhort, it muſt contain every thing required for the building of the place, and for its maintenance.

This memorial, together with the plan and profils of the ſituation, being laid before the council, which has the direction of ſuch works; who ought to ſend three or more of the moſt able engineers to the place, in order to examine every particular, and to obſerve, whether the plan and memorial are both conformable to the ſituation; if not in all particulars, to correct them; and when they are ſufficiently acquainted with every thing, to make a plan of the fortreſs, in conjunction, conformable to their inſtructions, and the conſequence of the place.

For it is my humble opinion, that ſuch an undertaking ſhould never be truſted to the judgment of one ſingle perſon, ever ſo well qualified, as it is too often the cuſtom; and when they all agree in their opinions, a fair plan is to be made on a ſcale of 30 fathoms to an

inch

inch at leaſt, with proper profils, in order to lay them before the council, with a new memorial, expreſſing their reaſons for making ſuch works preferable to any other, with references to the plan, and why the fortreſs is made of that extent.

But in caſe the engineers ſhould not agree in all the particulars; ſeparate plans muſt be made by each, and the reaſons given in writing, in order to be decided by the council, which of them is to be made uſe of; all this ſhould be done with the utmoſt candour, and without any views of intereſt, or preference in reſpect to capacity, or any thing elſe whatſoever, contrary to the true intereſt of the nation.

In making the plan of a fortreſs, particular regard muſt be had to the three following conſiderations:

1. *The expence neceſſary for the building of it.* For as it is generally very great in ſuch undertakings; by increaſing it without neceſſity, or the importance of the place requiring it, inſtead of being an advantage, it becomes a burthen to the nation.

2. *The number of troops required to guard and defend it, together with the quantity of artillery and ammunition for a ſiege.* For if this expence ſhould be equal to, or exceed the revenue or advantage ariſing from it; it is plain, that inſtead of being an advantage it would be a diſadvantage.

3. *The extent or capacity of the place, with reſpect to the ſpace taken up by the works of fortification.* For if it ſhould happen, as we are not without examples, that the town could not contain a ſufficient number of troops to defend it, beſides the inhabitants, it is evident, that it may be taken with leſs expence than another of fewer works, provided with the ſame number of troops; as each work would be capable to make a proper defence; and conſequently, a great expence would be thrown away on ſuperfluous works to no manner of purpoſe.

There are many other conſiderations to be had; as that the works ſhould flank or defend each other in the moſt direct manner poſſible; that the communication from the body to the outworks, may be eaſy and ſecure, as well as thoſe from one work to another: that the works are properly adapted to the nature of the ſituation; if the ground is low, tenaillous, lunets, or ſecond ditch and covert way, ought to be made; if level, ravelins and covert way only; if there are any hollow roads leading to it, ſome works that flank it in a direct manner; if there are any hills or riſing grounds that command ſome of the works, little forts or redoubts ſhould be made there, with a ſecure communication to the fortreſs; or elſe traverſes are to be made in the works themſelves, eſpecially, if they are ſeen in the rear: If the place is large and of great conſequence, horn or crown works are uſeful to ſecure the gateways, or a ſpot of ground which might be advantageous to an enemy: In ſhort, engineers ſhould be ſparing in their works, to make no more than what are barely neceſſary, and whereby viſible advantages are gained, both on account of ſaving expences in the building, and in the maintenance of a garriſon to defend it, and in every thing elſe neceſſary for its defence.

When an old place is to be fortified, that has ſome works ſtanding, the director ought to endeavour to find the reaſons which engaged the builder to make theſe works; which being known, he muſt conſider whether they anſwer the intent, and if not, how to change, either partly or the whole, ſo as to anſwer better, to make uſe of part of the old works, if not the whole; and never demoliſh old works to build new ones, without abſolute neceſſity, in order to diminiſh the expences. I have ſeen projects for demoliſhing old works and to build new ones in their ſtead, which were not ſo good by much; this will always happen, when an engineer is entruſted with works, that does not underſtand his buſineſs; and thoſe very people, are generally the moſt ambitious to ſhew their own performances, whether right or wrong.

Situations which are partly fortified by nature, ſuch as when there are any precipices, rocks, or which are partly ſurrounded with water, are very convenient; for the other part may be fortified at an eaſy rate, beſides the place requires but a ſmall garriſon to defend it. When the ſituation is rocky, care muſt be taken to make uſe of the rock for the facings of the works, as much as will agree with the plan, which will ſave expences; blowing up the higheſt parts to riſe the lower ones; but it muſt be taken notice, that each work is to be of the ſame level, or nearly ſo, every where, and that the inner ones riſe gradually above thoſe before them.

When the plan of a fortreſs is fixed upon, the profils muſt be determined, and it muſt be conſidered, whether the works are to be wholly faced with walls or partly, how much the height of the body is to exceed that of the outworks. Engineers vary very much in their opinions, in reſpect to the heights of the works; Mr. *Vauban* made the body of the place 6 or 8 feet higher than the ravelins, and theſe higher by 6 feet than the glacis: Mr. *Coehorn* did the ſame nearly, but made his capital ditch narrow and deep, whereas the former made it wide and ſhallow; the latter covers the wall of the body very much, ſo that it cannot be battered for above three feet below the horizon, brings the works cloſer to each other, and makes their defence ſhorter; the broad ditch, on the contrary, diſcovers the wall to the very foundation; but when the ditch is dry, works may be raiſed in it ſo as to make a good defence; the paſſage through it to the breach may be obſtructed and diſputed for a long while. As for my part, I think a middling width is preferable to a large one; that is, I would never make the capital ditch above 16 fathoms at the ſaliant angle of the baſtion, when the exterior ſide of the polygon is 180 fathoms, and ſo in proportion to the length of the ſides.

The reaſons given for making high ramparts, are, that they cover the houſes and other buildings better than low ones, and that the enemy may be fired at from all the works in the ſame front, without incommoding thoſe in the outworks. To this it is objected, that when the works riſe gradually one above the other, the enemy may ruin the defences all at once, from the firſt batteries he makes, and then may advance without having any thing elſe to fear than the fire of the ſmall arms; beſides the rampart of the place becomes very high, and of conſequence, increaſes the expences conſiderably.

On the contrary, if the works were made nearly all of the ſame height, the guns placed in the inner works cannot be diſmounted till the outer works are taken, excepting by ſhells; but the chance of diſmounting them is ſo very little, that it may be looked upon as inconſiderable.

Another material advantage ariſing from this method is, that the height of the body of the place is much leſs than the former, and therefore the expence of building it conſiderably diminiſhed: As to not being able to fire at the enemy from all the works at once, it is of no conſequence; becauſe the outward works will hold as many guns as are required to keep the enemy at a diſtance, and as he approaches, theſe guns may be brought into ſome others, when it is not ſafe to keep them longer there.

For my part, I would make the heights of the works ſo as to terminate in a right line drawn from the parapet of the body to the extremity of the glacis, becauſe by this means great expences would be ſaved; the enemy muſt batter the works one after another, and therefore raiſe as many batteries as there are works; beſides you may at any time fire *en barbet*

from

from any of the works you pleaſe, or is found moſt convenient.

Mr. *Vauban* uſed to raiſe his revetements as high as the parapets, excepting at *New Briſac*, where they are not above 3 or 4 feet above the level of the fields: and to build very ſtrong counterforts behind them; whereas Mr. *Coeborn*, who was more ſaving, made them only even with the level at *Bergen-op-zoom*.

This method is very good, becauſe it ſaves great expences in the building, and when the place is beſieged, the enemy can batter but a very little part of the wall; it requires more time to make a breach, and leſs expences to be repaired; whereas when the wall reaches quite up to the top, by battering it as low as can be, the upper part tumbling down all at once, makes a breach in a ſhort time; and the expence of repairing them is very great.

Some will have the walls to begin from the bottom of the ditch, without making very deep foundations: It is certain, that the burying ſo much maſonry under ground is of no other advantage than to ſupport the walls above them: And when a foundation can be made firm with piles or other ways, it would ſave great expences. This may be done in wet ditches, becauſe the wood being always under water will never periſh; but it is not ſo in dry ones, unleſs the bottom is very good, the piling cannot be depended on; beſides the foundations in the faces, where the breaches are made, ſhould be as deep as can be, becauſe the enemies miners will otherwiſe carry galleries under the wall and blow it up, in leſs time than the breach can be made by cannon: But in the gorges or counterſcarps where no breach can be made, nor any danger apprehended for making mines, it would be extravagant to lay the foundations any deeper than is juſt neceſſary to ſupport the walls above them.

SECT.

SECT. V.

To make the eſtimate of a FORTRESS.

WHEN the plan of a fortreſs is drawn with proper profils and elevations, and every thing expreſſed on paper that can be done, or is neceſſary; all the angles and lines not given by the conſtruction, muſt be found by trigonometry, according to the manner of the ſpecimen given in our *Elements of mathematics*, page 209: The quantity of maſonry muſt be computed in the manner taught, in page 261, as well as the excavation and tranſportation of the earth, and the expences of making the ramparts, parapets and glacis: then if the prices of the ſeveral materials are known in the country where the fortreſs is to be built; it will be eaſy to make a proper eſtimate of the expences that a ſtate will be at, in order to have the work executed.

As it is impoſſible to determine the prices of the materials, which change in every place, according as they are near or upon the ſpot, and as the labour is dear or cheap; we ſhall content ourſelves here, to give only the quantity of work of all the material parts; which together with the experience an engineer muſt have before he is employed in ſo great an undertaking, and the knowledge of the form uſed in the country, to repreſent it to the directors of theſe kind of works in a proper manner, will be ſufficient for our reader to underſtand what is neceſſary upon ſuch an occaſion.

To compute the QUANTITY *of* MASONRY.

Plate VI. Fig. 1. We ſhall ſuppoſe, that the fortreſs is a regular pentagon, with ravelins, covertway

and glacis; that the exterior ſide AB is 180 fathoms, the faces AH, BE, to be 50; the perpendicular CD, 30, according to Mr. *Vauban's* firſt method. Now becauſe we have found in our *Elements*, page 211, the flanks to be 27.27 fathoms, and as there are 10; the ſum of their lengths will be 272.7 fathoms, or becauſe, we ſhall expreſs all the contents by cubic yards, which is the uſual method here in *England*, and each fathom is two yards, the ſum of the lengths of all the flanks will be 545.4 yards: We have likewiſe found in the ſame page, that the length of the curtain FG, is 76.39 fathoms; and as there are five, the ſum of their lengths will be 381.95 fathoms, or 763.9 yards: And ſince the faces AH or BE, are 50 fathoms by conſtruction, the ſum of 10 faces will be 500 fathoms, or 1000 yards.

It may be obſerved, that it is the ſame thing to multiply each length by the number of ſquare yards contained in the profil, or to multiply the ſum of all the lengths, by the ſquare yards contained in the profil; whence by adding the ſums of the lengths of the faces 1000, the flanks 545.4, and that of the curtains, 763.9, we ſhall have 2309.3 yards, for the ſum or total of all the lengths of the body of the place.

Fig. 2. Now if the height of the profil ABCD, be 30 feet, or 10 yards, from the foundation AD to the cordon BC; the reſt of the parapet is ſuppoſed to be of earth only; then if the wall is of ſtone, according to our tables, the thickneſs BC above will be 5 feet, and that AD near the foundation 11. In order to find the area ABCD, we muſt add the two parallel ſides AD and BC, which gives 16 feet, and multiply half the ſum 8 by the height AB, 30, which 240 ſquare feet, and ſince 9 ſquare feet make a ſquare yard; if we divide 240 by 9, we ſhall get $26\frac{2}{3}$ ſquare yards for the content of the profil; excluſive of the foundation ADIH, and the counterforts; therefore

if we multiply the total length 2309.3, found above by $26\frac{2}{3}$, we ſhall get 61581.3 cubic yards for the content of maſonry contained in the body of the place, excluſive of the foundation and the counterforts.

If we ſuppoſe the foundation A H to be 6 feet deep, and 12 broad, as they are rectangular we need but multiply the baſe 12 by the height 6, which gives 72 ſquare feet or 8 ſquare yards for the area of the foundation: and therefore this content multiplied by the total length 2309.3, gives 18474.4 cubic yards for the foundation. In order to find the content of the counterforts, we muſt conſider that their whole heighth H B is 36 feet; the length of the baſe H K, 8.6 feet according to our tables: and if the diſtances from the center of the one to that of the next be 16 feet, their breadth will be 4 feet by what has been ſaid in the firſt ſection: whence multiplying 8.6 by 4, we get 34.4, feet for the area of the baſe or $3.8\frac{2}{9}$ ſquare yards; and this multiplied by the number of yards, 12, contained in the height gives $45.8\frac{2}{3}$ for the content of one of the counterforts: The number of counterforts is found by dividing the total length of the works, by the diſtance between the center of one counterfort to that of the next: and ſince the total length has been found to be 2309.3 yards, and the diſtance $5\frac{1}{3}$; we ſhall have 433, for the number of counterforts; and as the content of all the counterforts is equal to the product of the content of one multiplied by their number; it follows that 433 multiplied by 45.84, gives 19860.2 yards for the ſum or total content of all the counterforts. Whence we get for the quantity of maſonry of the body of the place

The content of the	wall	61581.3.
	foundation	18474.4.
	counterforts	19860.2.
	Total content	99915.9.

Having found the quantity of maſonry contained in the body of the place, the next thing is, to find that contained in the faces of the ravelins, which we ſhall ſuppoſe 24 feet high, and whoſe profil is repreſented by the third figure, the thickneſs above BC near the cordon is 4 feet 4 inches, and near the foundation 9 feet 11 inches, the ſum of the two parallel ſides will be 14 feet, 3 inches, half of which multiplied by the height 24, A B, gives 171 feet, or 19 yards exactly, for the content of the area A B C D of the profil, excluſive of the counterforts and foundation.

Now becauſe the faces of the ravelins, are 51.75 fathoms, according to our *Elements*, page 215; and ten of them will be 517.5 fathoms, or 1035 yards; this length being multiplied by the area 19 of the profil, gives 19665 cubic yards for the content of maſonry of the five ravelins, excluſive of the foundation and counterforts.

Suppoſe the foundation to be ſix feet deep, and 11 broad; then the product of 11 multiplied by 6, gives 66 feet for the ſection of the foundation, or 7 $\frac{1}{3}$ ſquare yards; now if this content be multiplied by the total length 1035, we ſhall have 7590 cubic yards, for the content of the foundation.

The length L A of the counterforts is 7 feet, and the height H B 30, including the foundation; therefore the area of the counterfort K B, will be 210 feet, or 23 $\frac{1}{3}$ ſquare yards; and if the diſtance of the center of one counterfort to that of the next be 16 feet, the thickneſs will be 4 feet, or 1 $\frac{1}{3}$ yard; whence multiplying 23 $\frac{1}{3}$, by 1 $\frac{1}{3}$, we ſhall get 31 cubic yards nearly, for the ſolid content of one counterfort. If we divide the total length 1035, by the diſtance $\frac{16}{3}$, we ſhall get 194 for the number of counterforts contained in the ravelins; and therefore this number 194, multiplied by the content 31 of one, gives 6014 cubic yards, for the total content. Conſequently, the quantity of maſonry contained in the faces of the ravelins will be

The content of the	wall	19665
	foundation	7590
	counterforts	6014
		33269

It remains now to find the quantity of maſonry contained in the counterſcarp; ſuppoſe the fourth figure to be the profil, which is 16 feet high, from the foundation, 2 feet above, and 5 feet 2 inches near the foundation, according to our tables; the two parallel ſides being added, gives 7 feet 2 inches, half that ſum multiplied by the height 16 feet, gives $57\frac{1}{3}$ ſquare feet, for the area, or 6.4 yards nearly.

The length of the counterſcarp is not found without a good deal of calculation, which we have explained in our *Elements*, pages 214, 215, and 216; to which we refer our reader, and content ourſelves by giving the amount as found there, for the length before one front, which is 290 fathoms, or 580 yards; and as there are five fronts, five times this number, gives 2900 yards for the total length; this length being multiplied by the content 6.4 of the profil, gives 18560 cubic yards for the content of the wall, excluſive of the foundation and counterforts.

If the foundation is 5 feet deep, and 6.5 wide; then the product of 5 by 6.5 gives 32.5 ſquare feet, or 3.6 ſquare yards nearly, for the ſection of the foundation; and this number multiplied by the total length 2900, gives 10440 cubic yards for the total quantity of maſonry in the foundation.

Now becauſe the height of the counterforts is 21 feet, and their length 4; the product of 21 by 4, gives 84 ſquare feet, or $9\frac{1}{3}$ ſquare yards for the area of the counterforts; and if we ſuppoſe as before, the diſtance from the center of one to that of the next, to be 12 feet, their thickneſs will be 3 feet or one yard; therefore the content of one counterfort will be 9 $\frac{1}{3}$ cubic yards.

If the total length 2900 yards be divided by 4 yards, their diſtance, we ſhall get 725 for the number of counterforts, which being multiplied by the content 9 $\frac{1}{3}$ of one, gives 6766.6 cubic yards, for the total content of maſonry in the counterforts. Hence the total content of the maſonry contained in the counterſcarp will be

Content of the	wall	18560
	foundation	10440
	counterforts	6766
	Total	35766

Having thus found the quantity of maſonry contained in the ſeveral parts, according to the plan and profils here given, by adding them together, we ſhall have the content of the whole, excluſive of bridges, gates, and under-ground works.

Content of the	body	99916
	ravelins	33329
	counterſcarp	35766
	Total content	168951

Theſe computations may alſo be performed as follows; add the areas of the profil and foundations to that of one counterfort divided by 4, and the ſum multiplied by the total length, gives the whole content at once. Thus in the counterſcarp, the area of the profil is 6.4 yards, that of the foundation 3.6, and that of the counterfort 9 $\frac{1}{3}$, this laſt divided by 4, gives 2.3 $\frac{1}{3}$. Now the ſum 12.3 $\frac{1}{3}$ of theſe three areas multiplied by the total length 2900, gives 35766 cubic yards, for the whole content of the counterſcarp; which is the ſame as before: The ſame thing will be true in regard to the reſt of the computations.

Although this is not the exact content of the maſonry contained in this fortreſs, becauſe there are ſolids in every angle, ſuch as are repreſented in the fourteenth plate of our *Elements*, which muſt be conſidered when the works are meaſured, as well as the coping ſtones; yet this menſuration is ſufficient for an eſtimate. There are many engineers that are not ſo exact in their computation; for how could it be, ſince few of them have ſcarcely the leaſt notion of geometry, without which, it is impoſſible to compute to an exactneſs any thing of this kind.

To compute the EXCAVATION *of the* DITCHES.

The method of computing the quantity of earth contained in the ditches of the body of the place, and ravelins, is reduced to the finding their areas, and then to multiply the ſum by the depth of the ditch, that is, by 16 feet, or 5 $\frac{1}{3}$ yards. But by reaſon of the irregular figures, they muſt be divided into parts, in the following manner. From the point B draw B L perpendicular to the counterſcarp; from the angle F of the flank F draw F T, perpendicular to the line of defence G E, and from the point D, D V perpendicular to the counterſcarp I L produced; then if B K be the capital of the baſtion produced, we muſt find the ſpace I L B D, the triangles G E F, D G H, and the circular ſector L B K, in order to get the area of the great ditch before one of the fronts.

The length I L of the counterſcarp has been found in our *Elements*, page 214, to be 87.85 fathoms, or 175.7 yards, B L is 40 yards by conſtruction; and in the right angled triangle D V I, we have D I, 25.93 fathoms, or 51.86 yards, by page 215; and the angle D I V, 74 degrees and 35 minutes; by which we find the perpendicular D V to be 50 yards, and the baſe I V 13.78, by adding I V to I L, we ſhall have V L, 189.48; and if we add the two parallel ſides B L, D V, we get 90, and half their ſum 45, multiplied by V L, 189.48, gives 8526.6 ſquare yards, for the ſpace D V L B, from which we muſt ſubtract the triangle D V I, in order to get the ſpace D I L B; but the ſide I V, is 13.78, and the perpendicular D V, 50; half the product of theſe numbers, gives 344.5 for the area of the triangle D V I, which being ſubtracted from the content of the area V L B D, leaves 8182 ſquare yards for the content of the ſpace D I L B.

The next thing to be found is the area of the triangle G F E, in which the ſide F G is 76.39 fathoms, or 152.78 yards, the ſide E F, 54.54 yards, and the ſide E G, 170,28 yards; having the three ſides of a triangle, the ſegment E T is found by ſaying the ſum 207.32 of the ſides G F, F E, is to their difference 98,24, as the baſe G E, 170.28 is to the difference 80.6; between the ſegments G T, and T E, which being ſubtracted from the baſe G E, 170.28, gives 89.68, half of which 44.84, will be the leſſer ſegment E T; therefore the difference between the ſquares of E F, 54.54, and E T, 44.84, will be equal to the ſquare of the perpendicular F T; which will be found to be 31 yards. Now becauſe the two triangles G F E, D G H, have the ſame altitude, the ſum of their baſes G E, 170.28, D H, 89.74 being multiplied by the perpendicular F T, 31, half the product, gives 4030 yards for the content of the ſpace E F G H D.

It remains now to find the circular ſector L B K; the angle L B K in a pentagon, is 108 degrees, and 52 minutes, and the radius B L, 40 yards by conſtruction; whence if we ſay 7 is to 22, ſo is the radius B L, 40, to the ſemi-circumference 125.7 nearly; and again, 180 degrees is to 108 degrees 52 minutes, or 108.86 degrees nearly, as 125.7, is to the arc L K, which is 76 yards; then half the product of this arc, and the radius gives 1520 ſquare yards for the content of the ſector L B K.

Now if we add twice the ſum of the ſpace DILB, 8182, and the ſector LBK, which is 19404, to the ſpace HGFED, which has been found to be 4030, we ſhall have 23434 ſquare yards for the great ditch, before one of the fronts.

Laſtly, The area of the ravelins ditch is to be found; if from the extremities of the face NQ, we draw N*b*, Q*n*, perpendicular to the oppoſite counterſcarp, *an*: Then becauſe the width of the ditch is 24 yards by conſtruction; and the face NQ, has been found in our *Elements*, page 215, to be 103.5; the breadth being multiplied by the length NQ, gives 2484 ſquare yards, for the content of the area NQ*nb*.

In the right angled triangle N*ba*, the perpendicular N*b* is 24 yards, and the baſe *ab* has been found in our *Elements*, to be 8.72 yards; and half the product of theſe two ſides, gives 104.64 for the content of this triangle.

The angle NQR has been found to be 73 degrees, and 30 minutes; whence, if we ſay, as 7 is to 22, ſo is the radius 24 to the ſemi-circumference 75.4; and 180 degrees is to 106. degrees, 30 minutes, or 106.5 degrees, the meaſure of the angle *n*Q*m*, ſo is 75.4 to the arc *nm*, 44.6 yards; and half the product of this arc and the radius, gives 535.2 ſquare yards for the content of the ſector *n*Q*m*.

Now if we add the content of the triangle N*ba*, 104.64 to that of the rectangle N*n*, 2484, their ſum will be 2588.64; and twice that ſum added to that of the ſector *n*Q*m*, gives 5712.48 ſquare yards for the content of the ditch before the ravelin.

Therefore if we add the contents of the great ditch 23434 to that of the ravelin, we ſhall get 29146.48 ſquare yards for the ſum, and five times this ſum gives 145732.4 ſquare yards for the content of the ditches round the whole fortreſs.

If this content be multiplied by the depth of the ditch 16 feet, or $5\frac{1}{3}$ yards, we ſhall get 777239.4 cubic yards for the total content of the ditches.

This is not the content of all the excavations to be made; that of the walls, counterforts, and their foundations muſt likewiſe be conſidered; as there muſt likewiſe be room for the workmen to work, which cannot be leſs than two feet, beſides the thickneſs of the wall, the length and breadth of the counterforts; but the ſlopes of the walls are not to be taken in here, becauſe we have ſuppoſed the ditch to be dug perpendicular.

Fig. 2. Therefore if RT be the line terminating the height of the ditch from the foundation, we muſt find the thickneſs of the wall at T; which is done by adding one fifth of the height RM 14 feet, to the thickneſs BC above 5 feet, which gives 8 feet nearly, to which adding two feet more, according to what has been ſaid above, gives 10 feet, and this multiplied by the height KR 16 feet, gives 160 feet, or 17.7 ſquare yards. Now the foundation DH being 6 feet deep, and 12 broad, to which adding two feet on each ſide, gives 16, and this multiply by 6, gives 96 feet, or 10.7 yards nearly; this added to 17.7, gives 28.4 ſquare yards for the area of the profil; therefore 28.4 multiplied by the total length 2309.3 of the body of the place found before, gives 65584 cubic yards, for the quantity of earth to be removed on account of the wall.

The height of the counterforts KR is 22 feet, including the foundation, the length KH is 8.6 feet to which adding two feet more, gives 10.6; this multiplied by 22, gives 233.2 feet, or 26 yards nearly: Now becauſe the thickneſs of the counterforts has been made 4 feet, by adding two more on each ſide, gives 8 feet, or $2\frac{2}{3}$ yards, which multiplied by 26, gives 69.3 for the quantity of earth removed on account of one counterfort; and as there are 433 of them, we ſhall have 30007 cubic yards for the total quantity of earth. This quantity, added to that above, gives 955.91 cubic yards for the total quantity to be removed on account of the wall of the body of the place.

Fig. 3. To find the quantity removed in the ravelin, where the height RM is 8, and the thickneſs BC 4.4 feet; one fifth of 8 is 1.6, which added to 4.4, gives 6, to which adding two feet more, gives 8; this multiplied by 16, gives 128 feet, or 14.2 ſquare yards for the ſection of the excavation.

The foundation has been ſuppoſed 6 feet deep, and 11 broad, by adding 4 to 11, gives 15, and this multiplied by 6, gives 10 yards for the foundation; the ſum of 14.2 and 10, gives 24.2 ſquare yards, which being multiplied by the total length 1035, gives 25047, for the content of the excavation of the faces.

The height of the counterforts KR is 22 feet, and their length KH, 7, to which adding two more, gives 9, and the product of 22 multiplied by 9, gives 198 feet, or 22 yards; and ſince the thickneſs of the counterforts is 4 feet, by adding 4 more, gives 8 feet, or 2 $\frac{2}{3}$ yards, which multiplied by 22, gives 58.6, for the excavation made for one counterfort, and as there are 194 in all, this number multiplied by the content 58.6 of one, gives 11368 for the total excavation made for the counterforts in the ravelin. This added to the former, gives 36415 cubic yards for the total excavation.

Fig. 4. Laſtly, It remains to find the excavation made for the counterſcarp: The thickneſs above is 2 feet, to which adding 2 more, gives 4, this multiplied by the height 16, gives 64 feet, or 7 yards nearly. The foundation is 5 feet deep, and 6.5 broad, to which adding 4 more, gives 10.5, and this multiplied by 5, gives 52.5 feet, or 5.8 yards nearly; and the ſum of the foundation and the wall is 12.8 yards: and becauſe the total length is 2900 yards, the product of this number multiplied by 12.8, gives 37120 cubic yards, for the content of the excavation.

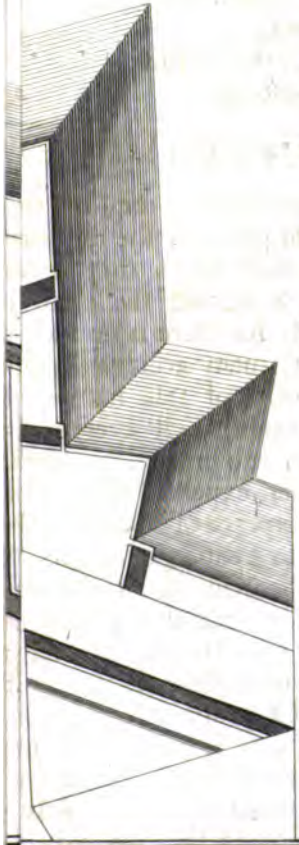
The height of the counterforts is 21 feet, and their length 4, to which adding 2 more, gives 6, the product gives 14 yards for the content; and as they are a yard thick, by adding a yard more, gives 2, and 14 by 2, gives 28 cubic yards for the content of one counterfort; and ſince there are 725, the total content of all the counterforts will be 20300. And this added to that of the wall 25047, gives 45347 cubic yards.

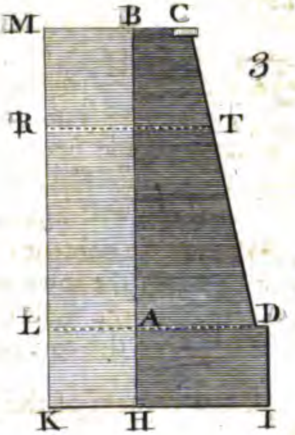
Whence the content of the ditches	777239
of the town-wall	95521
of the walls of the ravelin	36415
of the counterſcarp	45347
Total content of the excavation of earth	954592

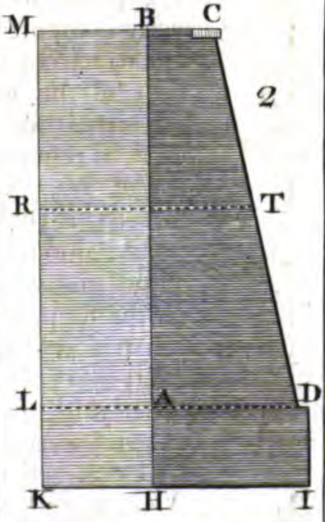
If it is known how many men are required to remove the earth, either from the glacis or the ramparts of the body and ravelin, and how much they remove in a day; the expence for removing the earth may be pretty exactly computed; for there is no ſuch thing as to form an exact account, many accidents happen during the time of the works of this nature, to come to any exactneſs; for example, if every cubic yard coſts ſixpence to remove, and make the works compleat, without any other expence either for tools, bridges, and roads; the expence of removing the whole quantity would amount to 23864 pounds, 16 ſhillings.

The computation of the quantity of earth has been made upon the ſuppoſition that the ground is level; but as this is ſcarcely ever the caſe in real practice, marks are left every where to ſhew the different depths that have been dug, and a proper reduction is made, in order to get the true quantity of earth removed; for which reaſon the reader muſt conſider what has been here done as the method by which he is to proceed when a fortification is to be executed; and that this is ſufficiently exact to make an eſtimate.

Plate VI







J. Couse Sculp

UNIV. OF MICH.

As to the maſonry, it may at all times be known what the ſtones coſt in the quarries, and for the bringing them on the ſpot; as likewiſe the expence of cutting them, and to make the walls, when the ſituation of the fortreſs is once fixed upon: the ſame thing will hold good if the place is to be built either entirely or partly with bricks.

But there are many leſſer articles, ſuch as the gateways, bridges, cazemats, powder-magazines, ſtore-houſes, guard-houſes, barracks, &c. which cannot be eſtimated without a great deal of experience in theſe kind of works: therefore an engineer muſt be well acquainted with it before he is able to undertake ſuch a work.

SECT. VI.

To trace the plan of a FORTRESS *on the* GROUND.

IF the ground is uneven, filled with buſhes, hedges, ditches, or any other obſtacles, which hinder the ſtations from being ſeen, it is neceſſary to trace the exterior ſides in a rough manner, in order to clear the ground, and then trace the works over again more exactly. If the fortreſs lies near a river, the ſide next to it muſt be traced firſt, ſo as to agree with the propoſed plan; or if there are any buildings which are to be incloſed, you begin with that ſide firſt, which brings them in their proper ſituation: The greateſt difficulties happen when the fortreſs is to be built on a deſcent of a rock or hill, where the works lie not all on the ſame level; in ſuch a caſe, great care muſt be taken to make proper allowances for raiſing and falling of the works, in order to place them in ſuch a manner that the exterior works be always commanded by the interior ones; it is here where an engineer requires great ſkill and knowledge to make the different parts anſwer their true intent.

There are two different inſtruments commonly uſed in tracing the works on the ground; which are the plain table and the theodolite.

The plain table is the moſt ſimple, but it is not ſo exact; for which reaſon, I would never uſe it, but in ſmall forts, or works of no great conſequence.

When a plain table is uſed, the plan muſt be drawn on a large ſcale, at leaſt of 30 fathoms to an inch, which is faſtened with ſealing wax to the table, ſo as to lay quite ſmooth and even; then by means of a ruler with ſights, the angles are laid down on the ground, and the lengths of the lines meaſured by a chain and rod: But when the theodolite is uſed, the lines and angles muſt be found by trigonometry, in the manner given in our *Elements of mathematics.*

This being done, the angles muſt be traced on the ground with the inſtrument, and the lines laid down as before. But to explain the manner of uſing both theſe inſtruments, we ſhall begin with the plain table, and ſhew how the body of the place is to be traced, and then how this is to be done with the theodolite.

To trace the PLAN *of a* FORTRESS *with a* PLAIN-TABLE.

Plate VII. Having faſtened the plan on the table, in the manner mentioned before; which we ſhall ſuppoſe to be a regular pentagon, of the ſame dimenſions as in the laſt plate: Suppoſe the point O to be the center of the place: place the table exactly over the point O, ſo as the center on the paper is exactly over the center on the ground, lay the edge of the ruler along the radius or capital O A, and turn the table round, till the point A is ſeen through the ſights,

place a piquet or ſtake in that direction; keep the table ſteddy, and turn the ruler about the center O, till it is in the direction O B on the paper, and place a piquet at any diſtance in that direction; keeping the table in the ſame direction, lay the ruler on the capital O C, and place a piquet in that direction, and proceed in the ſame manner with the capitals O D and O E; this being done, ſett off theſe capitals with a chain in the moſt exact manner you can, which gives the five points A, B, C, D, E; now to be certain, that theſe points were rightly determined, the exterior ſides A B, A E, &c. muſt be meaſured with the chain, and if they are the ſame length as they ſhould be, you are certain that theſe points are right: but if the exterior ſides are either too ſhort or too long, the capitals muſt be meaſured again, till ſuch time that every line on the ground is exactly of the ſame length as thoſe on the paper.

Having determined the exterior ſides, the table is placed at A, and by the help of the ruler turned ſo as the two exterior ſides A B, A E, on the paper coincide with thoſe on the ground; then keeping the table in that poſition, and laying the ruler along the face A F of the baſtion, and a piquet being placed in that direction; then the face A F is meaſured by the chain, which gives the point F; the table is placed over this point, ſo as the line A F on the paper agrees exactly with the ſame line on the ground; by keeping the table in that poſition, and directing the ruler along the flank F G; then a piquet is planted, and the length of the flank meaſured, which gives the point G.

After this the table is carried to the point B, and turned ſo as the exterior ſides B C, B A, on the paper agree with the ſame lines on the ground; keeping the table in that poſition, the ruler is directed along the face B L, and a piquet planted in this direction; then by ſetting off 50 fathoms for the length of the face, from B to L; the point L is given; to which the table being carried and turned ſo as that the face B L, upon the paper, agrees with that line, on the ground: then directing the ruler along the flank L H, and planting a piquet in that direction: by ſetting of 27.27 fathoms for the length of the flank from L to H, which determines the flank and curtain.

Now to be certain, that this front has been rightly traced, the diſtance from H to G muſt be meaſured, to ſee whether it is 76.39 fathoms as it ſhould be, and from the points A and B, it muſt be obſerved, whether the points B, L, G, and A, F, H, are in a right line; if this is ſo, the front is rightly traced, and if not, it muſt be traced over again, till every thing comes out right.

The ſame operations muſt be performed at every ſide of the place, by which the body will be finiſhed for the preſent, becauſe the rampart and parapet, as well as the thickneſs of the wall, are determined afterwards.

If the fortreſs is either irrregular, or there are any buildings in the way, in ſuch a manner, that the points A, B, C, D, E, cannot be ſeen from the center O: The exterior ſides A B, B C, C D, D E, muſt be traced; that is, the table is placed at A, in ſuch a manner, as the exterior ſide A E on the paper be in the ſame direction with A E on the ground; then, by keeping the table in that poſition, and directing the ruler along the ſide A B, in which a piquet is planted, and the lengths of the two ſides A E, A B, meaſured, which gives the points E, A, B; this done, the table is carried to the point B, and placed ſo as the ſide B A, on the paper agrees with that line on the ground; then the ruler being directed along the ſide B C, and its length being ſet off in that direction, gives the point C; in the ſame manner is found the ſide C D; and if the diſtance D E is found to be of its proper length, and the angle A E D agrees with that on the paper, the exterior ſides have been rightly determined: after this, the reſt is performed in the ſame manner as before.

If the poſition of any other line is determined either by buildings or a river, you are to begin with that line and find by its means the exterior ſide next to it, and from thence you proceed as before: Thus if the direction of the line C D is given, on account of a river, ſo as to bring the greateſt part of it into the great ditch; the table is placed at C, and directed ſo as the line C D on the paper agrees with that line on the ground; then keeping the table in that poſition, and directing the ruler along the exterior ſides C D and C B; the reſt is finiſhed as before.

When an old place is to be fortified, it often happens, that the ſituation of one of the curtains is determined; ſuppoſe G H; then the table is placed at G, and H, in order to find the flanks G F, H L; and then at L and F to find the faces L B, F A, which gives the exterior ſide A B; this being done, the reſt of the work is performed as before.

To trace the PLAN *of a* FORTRESS *on the* GROUND *with a* THEODOLITE.

When the fortreſs is regular, the theodolite is placed in the center O, and levelled by means of the croſs levels and ſkrews; fix the index to 360 degrees on the limb; turn the whole inſtrument round till the north end of the needle hangs over the flower de luce, or 360 degrees in the box; there fix the limb of the inſtrument by means of a ſcrew underneath, then diſcharge the index, and turn it about till the vertical hair in the teleſcope cuts the ſtation A placed any where in the direction O A; then adding the degrees on the limb, which we ſuppoſe to be a certain number of degrees exactly, without any fraction, to the number of degrees of the angle A O B, and turn the index ſo as to cut exactly the ſame number of degrees on the limb; this done, place a ſtation in the direction O B; adding again, the number of degrees of the angle B O C, to thoſe on the limb, and turn the index round, till it cuts the ſaid number, by placing a ſtation in the direction O C, and proceed in the ſame manner all round, till the whole is finiſhed.

We prefer this practice to any other, becauſe the needle cuts always the ſame number of degrees nearly, as the index does on the limb; but it may be done thus, after having levelled the inſtrument, and fixed the index to 360 degrees, you turn the inſtrument round till the vertical hair cuts any ſtation placed in the direction O A; then the limb is made faſt by means of a ſkrew, and the index diſcharged, and turned about till it cuts the ſame number of degrees as the angle A O B at the center, which is here 72 degrees; then placing a ſtation any where in the direction O B, and turning the index about till it cuts as many degrees as are contained in the angle A O C, which is here 144; by placing a ſtation in the direction O C, the index is turned round till it cuts the angle A O D, 216 degrees on the limb, and ſo on to the reſt; this done and a ſtation placed in O D; then, the index being turned round till the vertical hair in the teleſcope cuts the firſt ſtation A; if the index cuts exactly 360 degrees on the limb the angles are rightly laid down, and which it will always do, if the inſtrument has not been moved.

The angles at the center being laid down very accurately, the capitals OA, OB, *&c.* muſt be meaſured with the ſame care; and to prove the work, the exterior ſides A B, B C, *&c.* muſt alſo be meaſured, and if they anſwer their dimenſions, every thing is right. But if the fortification is irregular, or the points A, B, C, D, E, cannot be ſeen from the center O; the theodolite muſt be placed at any one angle as A, which we ſuppoſe to be determined by the ſituation, after the inſtrument is levelled, and the index placed on 360 degrees, the whole inſtrument is turned round till the north end of the needle points likewiſe at 360 degrees; the limb is faſtened, with the ſkrew and the index diſcharged, which being turned, ſo as the teleſcope cuts the ſtation in the direction A E, which is ſuppoſed to be given; then obſerving the number of degrees which the angle made by A E, with due ſouth and north, ſuppoſe 5 degrees, which being ſubtracted from the angle E A B, of the polygon 108 degrees, then turning the index round till it cuts 103 degrees on the limb, which is the difference between 5 and 108; then placing a ſtation in the direction A B, and ſetting off from A to B, 180 fathoms for the length of the exterior ſide A B: Now the theodolite being placed at B, and the index fixed to the limb, the whole inſtrument is turned, ſo as the ſtation at A may be ſeen through the teleſcope; then the limb is faſtened, and the index diſcharged, after having obſerved the number of degrees it points at, to which adding the number of degrees contained in the angle A B C, and if the ſum exceeds 360 degrees, ſubtract 360 from it, and turn the index round, till it points at the given number of degrees, and looking through the teleſcope, the ſtation C is placed in that direction: the exterior ſide B C being ſet off on the ground, gives the point C; from whence proceed in the ſame manner as before, till you come to the point E; and when the inſtrument is brought to the firſt ſtation A, and the angle E A B is found the ſame as before, the operation is right.

It may be obſerved, that by laying thus down the angles from the meridian, paſſing through the point A; the needle will always point at the ſame number of degrees nearly in the box as the index on the limb, which being carefully obſerved at every ſtation, will ſhew whether any error has been committed, either by accident or miſtake, and if there be any found you muſt return to the former ſtation to correct it, before you proceed farther; by which you ſave the trouble of going over the work again, for a miſtake made perhaps at the beginning. Moſt engineers content themſelves, by laying down ſimply, the angles of the polygon without any meridian.

As all the angles and lines of a plan muſt be found by trigonometry, when it is to be traced on the ground with a theodolite, you place the inſtrument at A, and ſet off the angle B A F, and the length of the face AF, and then at F, to make the angle A F G of the ſhoulder, and when the length of the flank F G is meaſured, the inſtrument is placed at the point B, and proceed in the ſame manner, to find the points L and H: then if the points B, L, G, are in the ſame right line as well as the points A, F, H, and the length of the curtain GH comes out right, you are certain, that no miſtake has been made: The ſame operations are performed with regard to any other front, by which the body of the place is traced on the ground.

The next thing in hand, is to trace the counterſcarp of the great ditch; which is done in this manner; make the angle MDN, equal to 74 degrees, 35 minutes, according to what is ſaid in our *Elements*, page 214; and ſet off from D to N twenty fathoms, for the width of the ditch, trace a line in the direction NR, perform the ſame operation before the face ER, and you will have the ſtrait part of the counterſcarp; the round parts before the baſtions are determined by placing piquets at certain diſtances from each other, ſo as to be 20 fathoms diſtant from the ſailant angles of the baſtions; or if the ditch is not ſo wide, and that the chain may reach croſs, faſten one end of it to the piquet at D, and at the other end a looſe piquet, ſo as to reach the point N; then by turning the chain round the piquet at D, ſo as to keep it always ſtrait, with the point of the other piquet you may trace the round part on the ground.

To trace the ravelin, through the middle of the exterior ſide DE, mark a line ST, at right angles to it, in which ſet off 50 fathoms, for the length of the capital of the ravelin, from the reentring angle S of the counterſcarp to the point T; from the point T, trace two lines to the counterſcarp, which when produced, ſhall meet the oppoſite faces of the baſtion in a point X, within three fathoms, from the ſhoulder M. As to the counterſcarp of the ravelins ditch, it is found by erecting perpendiculars at the extremities of the faces, each of 12 fathoms, for the width of the ditch: The round part is found as before.

To trace the COVERT WAY *and* GLACIS *on the* GROUND.

From the reentring angle *a* of the counterſcarp, ſet off 20 fathoms for the ſemi-gorges *a b*, *a c*, of the place of arms; faſten two chains or chords to two piquets placed at *b* and *c*, each of them of 25 fathoms long; which being ſtretched, and ſo as to meet at *d*, place a piquet there, and trace the faces *b d*, *c d*. If two points are marked with piquets along each ſide of the counterſcarp, and at 6 fathoms from it, then the lines traced in theſe directions will determine the covert-way: and ſetting off two perpendiculars to the ſides of the covert-way, and at 20 fathoms from them the lines traced through their extremities will determine the breadth of the glacis. The traverſes are eaſily traced on the ground, from their conſtruction on the paper.

This is the moſt accurate way of tracing the plan of a fortreſs on the ground; and it may be obſerved in general, that all works of what kind ſoever of this nature, are always to be traced, by the help of the lines and angles, either given by conſtruction, or found by trigonometry.

For inſtance, to trace a horn or crown-work, on the ground; the angle which their branches make, either with the counterſcarp or the faces of the baſtion, muſt be found as well as the length of the branches, theſe being once known and traced, the reſt may be performed in the ſame manner as in the body of the place.

The manner of tracing lunets, tenaillons, counter-gards, and all ſuch works, differs ſo little from what has been ſaid before, that it requires no farther explanation.

SECT. VII.

The METHOD *of building a* FORTRESS.

AFTER having traced the principal or magiſtral line of the works, the ground muſt be levelled round the body of the place, in order to chooſe a mean between the different raiſings and fallings of the ground for the level of the place, which ought to be ſuch that the earth of the higher parts may nearly fill up the cavities of the lower, and the center of the place muſt be marked, and is generally about ſix feet higher than the above mentioned level, in order to get a proper deſcent for the running of the water into the ditch; this being done, a trench is dug all round for the foundation of the body-wall; but care muſt be taken, to throw as much earth out of the trench and ditch, towards the center of the place, as will make the rampart and parapet; this may be done nearly by computing that part of the profil above the level ground, and cutting a trench of an equal ſection; it muſt likewiſe be conſidered, how much earth will nearly be dug within the place, for cellars, conducts, ſaly-ports and cazemats. For the removing the earth out of ditches and underground-works, in ſuch a manner, as juſt to

make

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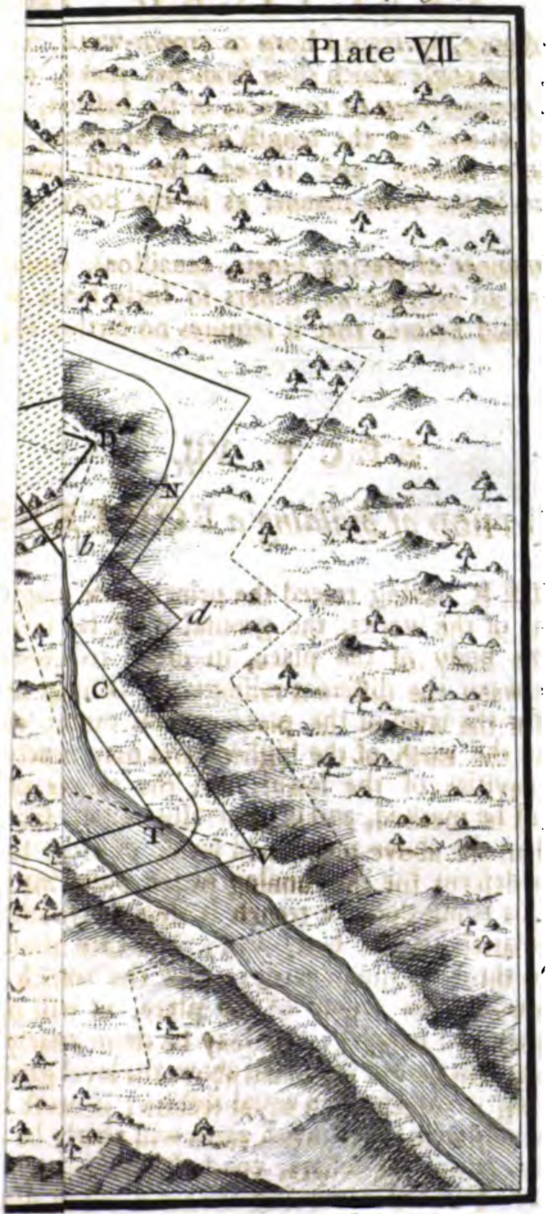
Plate VII

J. Couse Sculp.

UNIV. OF MICH.

make the rampart and parapet, and the reſt for the glacis, is one of the moſt difficult taſks that can happen; ſince it requires great ſkill to do it ſo as not to have more than is wanted to compleat the work, and to prevent the moving of it over again from one place where it was thought neceſſary, to another, which in my opinion, is hardly poſſible, and therefore the leaſt removes will be the beſt.

That part of the trench made for the foundation of any work towards the rampart, ought to be cut into ſteps, as may be ſeen in the eighth profil, Plate VIII. and as near the wall as can be, without any inconveniency; becauſe when the rampart is compleated, there will be only the earth which has been dug, that will preſs againſt the wall; whereby its reſiſtance becomes ſo much the ſtronger. In my opinion, the rampart ſhould not be made till ſuch time the maſonry is ſettled and dry, which requires at leaſt a twelve month, unleſs there is an abſolute neceſſity for it; for when the damp earth is rammed againſt a wet wall, it will require a great while before it dries, and perhaps this will not happen at all, unleſs the mortar be very good; for which reaſon, I would mix cinders inſtead of ſand with the lime, and to lay this mortar about a foot and a half deep on the ſide of the wall next to the rampart; this will ſooner dry, and prevent the moiſtneſs of the earth from penetrating into the maſonry.

To prevent the preſſure of the earth againſt the wall as much as is poſſible, branches of all kind of wood are ſtuck into the earth, by horizontal layers, with the ſharp end as deep into the unmoved earth, and as firm as can be, and a bed of earth well rammed, of half a foot deep; in the manner repreſented in the eighth profil; when this is done, the wall has time to ſettle well, and becomes quite hard before it ſuffers any preſſure.

Of the FOUNDATIONS *and the manner of laying them.*

Plate VIII. As the foundations of all buildings in general, are of the greateſt importance, in reſpect to the ſtrength and duration of the work; we ſhall enter into all the moſt material particulars, which may happen in different ſoils, in order to execute works with all the ſecurity poſſible; becauſe many great buildings have been rent into pieces, and ſome fallen down, for want of having taken proper care in laying the foundation; and for a further explanation we ſhall join here plans and profils, adapted to the moſt material ſituations that can be found.

Firſt, It is neceſſary to examine very carefully the nature of the ſoil, upon which the foundations are to be built; for doing this, proper augures are uſed to bore holes in ſeveral places 10, 12 to 15 feet deep, in order to diſcover the nature of the ſoil, and its hardneſs; or if it is made of ſeveral layers or ſtratas, which is commonly the caſe, the difference of their nature and goodneſs; this is known by their colour or the difficulty of piercing through them.

If the ſoil be of a good conſiſtence, for a certain depth, without any water or ſoft ground, and this holds ſo all round the foundation, there need no other precaution be taken, than to lay the foundation four, five, or ſix feet deep; only obſerving to enlarge its breadth, in proportion to the height of the walls to be built upon them: Since the higher the wall is the more weight the foundation muſt ſupport: Although this is ſelf-evident, yet engineers do not ſeem to mind it, becauſe they make commonly the baſe of the wall in proportion to the depth of the foundation, and not to the height of the wall.

If the ſoil be a hard gravel for about 10 or 12 feet deep, the foundation may be built upon it, without any danger of its ſinking; or if the ſoil be a ſtiff clay, it will likewiſe be good; the firſt and ſecond figures repreſent the profil and plan of ſuch a foundation; where there are two or three courſes of large ſtones to be put at the bottom; and the foundation projects by two or three feet before, divided into as many retreats, but not above a foot behind; becauſe there is no danger of the wall falling backwards; this is the cuſtom, but as for my part, I think there is no occaſion for any projection at all backwards; ſince the counterforts are ſufficient to ſupport the wall, and this projection might be of greater advantage before, if added to thoſe already mentioned.

If the ſoil be not very firm or hard to a ſufficient depth, or when ſome parts are ſofter than others; it will be neceſſary to lay a grate of timber firſt croſs ways, and then long-ways; or ſome lay them firſt long-ways, and then croſs-ways, which ſeems to be beſt, and well bolted together with wooden trunnels, as is repreſented in the third and fourth figures: Sometimes, theſe grates are boarded over with three inch planks, as is marked in the profil; at others large ſtones are laid between the timbers of the grate, and laid even with them, upon which the foundation is afterwards raiſed.

Some engineers, chooſe to raiſe the fore part of the grate of about a twenty fourth part of its breadth, in order to prevent the wall from being overſet by the preſſure of the earth, as it has ſometimes happened: this precaution ſeems to me to be very neceſſary, eſpecially when the rampart is pretty high; and the courſes of ſtone in the foundation ſhould have the ſame inclination, excepting the laſt, or the baſe of the wall ought to be level, if thoſe of the wall are ſo. I am ſenſible, that ſome engineers ridicule this practice, and ſay, that all beds of ſtone or brick ſhould be exactly in a level; but Mr. *Coehorn*, who knew more of this matter than moſt, if not all of our modern engineers, has not only laid his foundations in this manner, but likewiſe the walls quite up to the top. This is confirmed by *L'abbé Dedier*, in his perfect *French* engineer, where he ſays, that in repairing the works at *Manheim*, which were built under the direction of Mr. *Coehorn*, they found that the courſes of maſonry where perpendicular to the outward ſlope, whoſe baſe is one ſixth part of the height, and the walls were only about three feet thick above, without any counterforts. This being the caſe, and the walls being ſtrong enough to reſiſt the preſſure of the earth, this manner of laying bricks or ſtones, has greatly the advantage over that commonly uſed.

If the ſoil be ſand, and of no hard conſiſtence; the grating the foundation is abſolutely neceſſary; or if the ſoil be a ſoft loom or common earth, it is alſo neceſſary to take this precaution; and in general, when the ſoil is doubtful, though not abſolutely bad, a grating ſuch as this cannot but be very uſeful in preventing the walls from ſinking; and I muſt repeat it again, when the wall or rampart is very high, particular care ſhould be taken to ſecure the foundation in the beſt manner poſſible; for it is better to do this, though ſomewhat more expenſive, than to run the chance of making bad work at an eaſier rate, which might prove more burthenſome at the end.

It is neceſſary to obſerve, that when there is any timber under the foundation, the firſt courſe of ſtones ſhould be made without mortar, becauſe its coroſiveneſs deſtroys the wood; and in general, where any beams or timbers are laid into the maſonry, inſtead of mortar, ſtiff clay is uſed round it; and ſome carpenters make thin caſes of wood round the parts which enter into the wall.

When the foundations are ſo very bad, that the grate of timber mentioned before is not ſufficient, but is hard after a certain depth; upon ſuch an occaſion, it is proper to drive piles, and then lay a grate over them, ſuch as is repreſented by the fifth and ſixth figure;

theſe piles are to be placed exactly under the croſſings of the timbers, to which they are faſtened with trunnels, and are to be drove into the ground as far as they will go..

As this method of laying foundations happens moſt frequently in the works of a fortreſs, and is very expenſive, care muſt be taken not to make any more than what is neceſſary. In order to find the proper length of the piles, one or two are drove as deep as they will go, and then cut a certain number of the ſame length, and when theſe are drove, and the depth of the foundation remains the ſame, more are cut of the ſame length; but if the foundation changes, the reſt muſt be made accordingly. By this method a good deal of timber may be ſaved; whereas, if the piles are all cut at once, ſome will happen to be too long, and perhaps ſome too ſhort, which waſtes a great deal of timber to no manner of purpoſe.

Some engineers drive piles into every corner of the ſquares formed by the timbers, and none under the frame, as is repreſented here; but this method muſt appear by every judicious reader, not ſo good as the former, becauſe the frame is ſupported by nothing but the earth, which being but ſoft, muſt give way to the great weight of the wall preſſing upon the frame.

Others drive not only piles under the grate, as we have ſaid above, but likewiſe two in every ſquare, that is, in the oppoſite angles; but it ſeems to me, not worth while to make ſuch expenſive work without an abſolute neceſſity, and when no other method is practicable.

Beſides the piles under the grating, others are to be drove at the outſide next to the ditch, as is repreſented in the plan by the letter *a*, their number is uncertain, and ought to be regulated by the goodneſs or badneſs of the foundation. In both foundations, repreſented by the third and fifth profils, the outſide timber next to the ditch, ought to be cut in ſuch a manner that the wall may reſt upon part of it, and the other part prevent it from ſliding into the ditch, or elſe a ſmaller timber ſhould be faſtened with bolts upon the larger. Mr. *Belidor* gives an example of a wall ſliding in the ditch, at *Bergue St. Vinoc*, in *Flanders*, which was the face of a ravelin; the ſame thing happened ſome years ago, at our wharf here, at *Woolwich*, for the middle part of it, ſlid five or ſix feet into the *Thames*, becauſe the foundation was only clay rammed even with the bed of the river, and which would have been ſufficient, had the precaution above mentioned been taken.

We have mentioned before that ſometimes planks are uſed to cover the grating, and ſometimes not; where there is plenty of ſtones, theſe planks may be ſaved; but in walls made of brick they are abſolutely neceſſary; for they being but of a ſmall ſize, thoſe which reſt upon the timber will not be able to ſuſtain thoſe which are between them.

If the foundation is either all rock, or only partly ſo; the bed of the wall is to be ſunk about 6 inches or ſomething more into it, in the manner repreſented by the ſeventh figure, to prevent the wall from ſliding, which otherwiſe might happen, becauſe maſonry ſeldom binds ſo well with the rock as to make it firm and durable. When the bed is made, care muſt be taken to ſweep it very clean, in order that no rubbiſh or duſt remains in it, and after this, it muſt be wet as the wall is made; by doing ſo, the mortar will enter better into the pores and ſmall cavities, the maſonry will likewiſe bind with the rock in a more eaſy manner, and form in time but one continued ſolid ſtone.

Although rock is the ſtrongeſt foundation that can be built upon, nevertheleſs, engineers look upon it as one of the moſt difficult pieces of work to be met with; their reaſon for thinking ſo is, that they are ſeldom level, but raiſe and fall continually, by which the work changes its profil at every ſmall diſtance, and to raiſe the foundation to a proper level, and bind the maſonry to the rock in a ſtrong and firm manner, meets with the greateſt difficulty.

The ſecureſt manner of proceeding in ſuch a caſe, is, to clear the rock as well as can be, from all duſt and rubbiſh, in the manner obſerved before, and to ſink from four to ſix inches into it; then raiſe the lower parts with good maſonry made of very thin but ſtrong mortar, ſo as to be in the ſame level with the higher ones. This work muſt be left ſome time to dry and ſettle, otherwiſe, that part of the wall which ſtands upon the made foundation will ſink and break off from the parts which ſtand upon the rock.

Sometimes the rock will riſe at one end nearly as high as the wall itſelf; in this caſe, the work muſt be raiſed to a level, of about ſix feet from the bottom, and then left to dry and ſettle for ſome time; after that, it may be raiſed to the ſame height again till ſuch time as the whole wall is finiſhed; and to prevent the workmen from ſtanding ſtill, ſeveral parts may be undertaken at the ſame time and carried on alternately.

Sometimes it happens, that the rock riſes gradually behind, nearly as high as the wall, or, which is the ſame, that a wall is to be built againſt the rock; in this caſe, the rock muſt be well cleared from all dirt and rubbiſh, and if it is too ſmooth, it muſt be pickt, or ſmall cavities made in it, that the mortar may lay hold of, and bind it with the maſonry; and the work muſt be carried on gradually and ſlowly, otherwiſe the maſonry will naturally ſink and tear off from the rock.

Mr. *Belidor* propoſes a method for building walls in this caſe, which, he ſays, has often been practiſed by ſome *French* engineers with good ſucceſs; that is, inſtead of uſing common mortar and ſtone in the uſual manner, they prepare what is called ſtone-mortar; which is made of thin but ſtrong mortar, mixt with ſtones, about the ſize of a wallnut, a little more or leſs;

then

then they ſet a kind of coffer without a bottom, cut underneath, ſo as to agree nearly with the unevenneſs of the rock; then this coffer is filled with mortar, and let ſtand till it is dry and pretty hard; then they take the coffer away, in order to place it elſewhere. The reader may eaſily perceive, that the ſurface of this mortar is laid ſmooth and level, and that, when it is well ſettled, will ſtick much better to the rock than any other kind of work whatſoever; theſe kinds of walls become in time as hard as ſtone itſelf, as appears by the remains of ſuch as have been found here, in *France*, and in *Germany*.

In ſome parts of *Scotland*, in *Ireland*, at *Gibralter*, and *Mahon*, the rocks are generally of lime ſtone; in ſuch a caſe, no better work can be made, than to mix the ſtones of the ſame rock with the lime; this will, by the likeneſs of the parts, form a work that will join to the rock, and in time become as one continued ſtone.

It happens ſometimes that under a bed of gravel, clay, or any other hard conſiſtence, there is a ſoft watery ſoil or ſand, to a great depth; where it would be dangerous to drive piles, on account of the ſources or ſprings, which are generally under theſe places, which when they get once a vent or opening, fill the trench made for the foundation in a ſhort time, full of water, in ſuch a manner, as there is no poſſibility to build there. When this happens, a gutter muſt be made to lead the water out of the trench into ſome well made for that purpoſe, if none is found near enough, and engines ſet to work to draw the water out of it into ſome lower place or ditch.

It may happen, that the water comes ſo faſt into the trench, as not to be drawn off; in both caſes, a ſtrong grate of timber muſt be made, and planked over, which being laid over the foundation, and faſtened in ſuch a manner, as not to ſhift its place, then the maſonry is built upon it, by which it will ſink gradually,

dually, till it comes to the ground, and when the foundation is raiſed above the water, it is left to dry and ſettle before the wall is continued.

I have been aſſured by people of veracity, and judges of theſe works, that many ſuch inſtances happen in *Ruſſia*, as well as in *Flanders*, and yet when the walls are finiſhed, they ſtand neverthelefs as firm as if they were built upon a ſtrong foundation; it is certain, that theſe walls will ſink, but then the buſineſs is to make the whole go together without clinks or breakings; which can no otherwiſe be done, than with very good materials, and great care and induſtry.

Notwithſtanding that no water appears above ground, and that there is only a hard cruſt of five or ſix feet deep over a ſwampy ſoil, yet it is neceſſary to lay a ſtrong large grate under the foundation; by taking care to ſink the trench as little as can be done, for the ſafety of the work; and the foundation muſt be carried all round alike by horizontal courſes, and no new one begun before the laſt be quite finiſhed, ſo that if the ground underneath gives way, it may be preſſed alike every where, and ſink together.

This method of carrying on the foundation alike all round the work, ſhould be obſerved every where, excepting on rocks, or ſuch a hard ſubſtance that cannot give way, where it may be done by parts one after another; only obſerving to join them well together, and by ſteps, that no two joints may be over one another.

There are ſome ſituations, which beſides being ſwampy, the trench dug for the foundation fills in a ſhort time with water; the method uſed upon theſe occaſions, is, to open only as much of it as can be made in a day, and the ſtones are laid, without any other precaution, on the ground, and the work is carried on as faſt as poſſible, till the wall is above the height to which the water riſes; but this foundation muſt be made very broad and by retreats; and the ſtones laid in terraſs mortar, that it may ſoon grow hard; when this is done all round, and the work ſettled, the reſt is built in the uſual manner.

Theſe kind of foundations, are very common in *Flanders*, and Mr. *Vauban*, was very much puzzled at firſt how to proceed, till ſome workmen of the country, which had been uſed to them, put him in a method of it: I have ſeen the ſame at *Douay*, where they dug a trench of about 40 yards, and three feet deep; and as faſt as it was opened the maſons worked at the foundation, which was raiſed ſix feet high; though the next day half of it was under water, yet the work ſtood as well as if it had been built upon a ſolid foundation.

As the different ſituations and ſoils require different precautions, it is impoſſible to give particular methods for every one; the moſt ſecure and probable, by which an engineer may ſucceed, is, to conſult the workmen, who either live upon the ſpot, or near it, and who have been employed in ſuch foundations; for they generally know beſt, what method will moſt likely ſucceed; by conſulting ſeveral upon the ſame ſubject, if they differ in their opinion, which is often the caſe; it is the engineers buſineſs to judge what is beſt to be done, and from his own experience, joined to that of the workmen, deduce the method, by which he is to carry on his work: But, notwithſtanding all human precautions that can be taken, yet accidents will happen, which are to be repaired as ſoon as poſſible, and whereby the engineer will learn how to avoid them afterwards, in the remainder of his works.

We have endeavoured to give here moſt of the ſeveral caſes, which commonly happen, in all foundations made upon the land; and which, if ſtudied with care, I do not doubt, but an engineer with a moderate ſhare of practice and knowledge, will be enabled to perform ſuch works: But the manner of laying the foundations in water for bridges, ſluices, moles, and

piers

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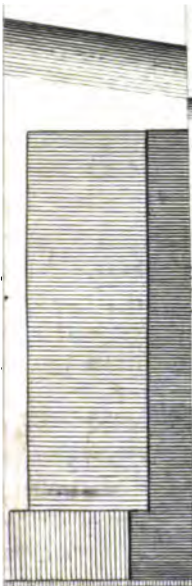
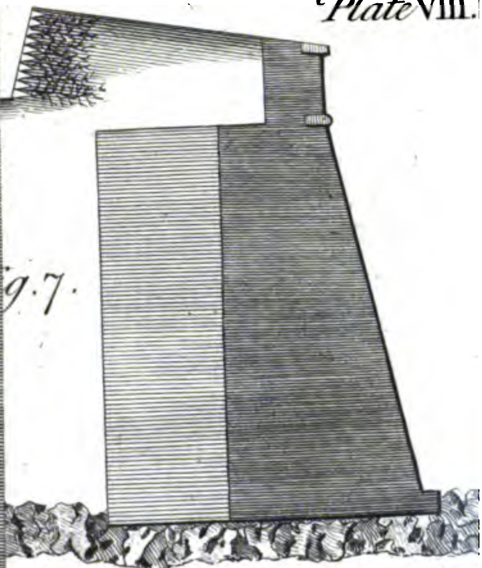
Plate VIII.





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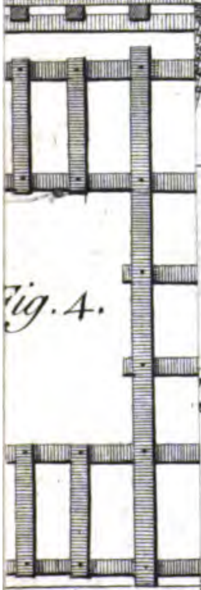

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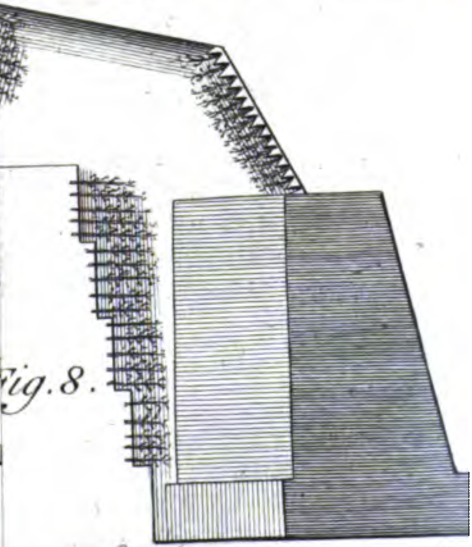

ig.8.

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piers for harbours, will be treated of ſeparately in the latter part of this work.

How to carry on the WORKS *of a* FORTRESS.

The firſt thing to be done, is to know what part of a fortification is to be built firſt: Some engineers begin with the covert-way, and ſecure it with palliſades, in order, they ſay, to prevent the enemy from diſturbing them in carrying on the works: This reaſon may do in time of a war, and in a place where the enemy can come at; but in a time of peace, it is entirely groundleſs, becauſe it is a difficult matter to know exactly how much earth is required to make the rampart of the body of the place, and thoſe of the outworks; and therefore by leaving either too much, or too little, the carrying it afterwards to their proper places cauſes a great deal of ſuperfluous expences, entirely owing to the want of ſkill in the engineer.

Others chuſe to begin with the flanks, and then go on with the faces of the baſtions, that in caſe an enemy ſhould endeavour to diſturb them, they might keep him off by means of the guns placed therein: This may do very well when the foundation is good, but would by no means be proper, where they are bad, for the reaſons given before; becauſe if one part ſhould be built before the whole foundation is laid, it would be ſettled before the next is finiſhed, by which the laſt would break off from the former by its ſettling: This will even happen, when the foundations are good; it is certain, that when the foundations are once laid all round, of about ſix feet high, and well ſettled; then the reſt of the wall of the baſtions may be finiſhed firſt; and foraſmuch, that when they are full, require a great quantity of earth, which is eaſily carried through the curtains; whereas the earth for the ramparts of the curtains cannot ſo well be carried through a paſſage in the baſtion; but, however, every engineer may have his particular reaſons, for beginning the works ſooner one way than another.

When the foundations of the body of the place are laid, the firſt thing to be done is, the openings for the common ſhores in proper places, to carry off the filth and rain water of the ſtreets; and it muſt be particularly obſerved to give them a proper deſcent, from the center of the place towards the ditch, that the water may carry off the mud, otherwiſe they will ſoon choak up, and require continual cleaning; and they ſhould always be carried either under or near the places where the bog-houſes are to be made, that the water may carry off the filth, and prevent their ſtinking in warm weather, and to be nauſeous to the inhabitants.

If there are any powder-magazines to be made in the baſtions, or any other building, ſuch as an hoſpital for the ſick and wounded in time of a ſiege, or ſtore-houſes to lodge ammunitions in, they muſt be built at the ſame time as the baſtions; in order that there may be no uſeleſs removings or diggings of earth, which would create ſuperfluous expences. If there are galleries for mines to be made in any of the works, they ſhould be begun at the ſame time: In general, all under-ground works ſhould be firſt conſidered, and begun as ſoon as the foundation of the walls are laid: For which reaſon, not only the plan and profils of a fortreſs ſhould be made at firſt, but likewiſe, drawings of the moſt minute parts of all the neceſſary buildings, which depend on the fortreſs, with their dimenſions marked upon them, and expreſſed in the eſtimate.

SECT. VIII.

METHOD *to be obſerved in making* MASONRY.

HAving entred into all the moſt neceſſary particulars of the materials uſed in the building of a fortreſs, we ſhall now ſhew how they are to be applied in the beſt manner; and as ſtone maſonry is by much the greateſt part, we ſhall begin with that firſt, and then proceed with the reſt, each in their order.

As maſonry made of hewn ſtones is certainly the beſt, but at the ſame time ſo expenſive, that few works are hardly ever wholly built with them; for which reaſon, engineers content themſelves to make the lower part of the wall of them, for about 8, 10 or 12 feet high, as likewiſe the ſailant angles quite up to the top: and the hardeſt ſort are chiefly uſed at the angles, and in thoſe places where a ſtrong current, or the ſea can beat againſt them: For if the ſtones are not very hard, the water ſtriking with a great velocity, in an oblique direction, wears them preſently out; as may be ſeen at *Portſmouth*.

Maſons diſtinguiſh their hewn ſtones by two names, *viz.* ſtretchers and headers; that is, ſuppoſe a ſtone to be twice as long as it is broad, then if it be laid ſo as the length goes into the wall, it is called a ſtretcher, but if the length appears on the ſurface of the wall, it is called a header. Theſe ſtones are laid alternately, a header, then a ſtretcher, through the whole length of the wall; and at the angles, that which is a header one way is a ſtretcher another.

The engineer or his overſeers, ought to be very diligent, to ſee that theſe ſtones are well ſquared, and when they lay them, that they bed well, that is, that they lay quite flat on each other; for the maſons often are very careleſs in their work, either for the ſake of ſpeed, or out of meer idleneſs; and when the ſtones are laid, and bed not well, they put wooden wedges under the corners, to ſave the trouble of removing and ſquaring them a-new; which ſhould be prevented as much as poſſible; otherwiſe a wall can never be ſtrong, and firm, and therefore has not a proper ſtrength to reſiſt the preſſure of earth which is againſt it.

The ancients were ſo very nice in all their publick buildings, that no joint ſcarcely ever appeared; which they did by rubbing the joining ſurfaces againſt each other, and laid the ſtones without mortar, leaving the outward ſurface rough, till the ſtones were all laid, and then made it ſmooth: But this precaution is never taken now-a-days, for which reaſon, no modern building comes up to thoſe built by the ancients, either for beauty or ſtrength: For you may ſee in the fineſt buildings in *England*, the joints in columns or pilaſter, half an inch wide, filled with very bad mortar, which by the weather has been wore out in a ſhort time, to the great ſhame of the modern architects.

The beſt ſtones being uſed in the facing, the reſt is made with ſmall ſtones, called rubble; but care muſt be taken, that this ruble work is well performed, in making the workmen chooſe thoſe which lay cloſe to each other, and that they fill up every part as well as they can, and not by a quantity of bad mortar, as they certainly will, if not prevented.

If the walls are to be built in water, the ſtones muſt be laid with terraſs mortar, thoſe parts which are ſometimes dry and ſometimes wet may only be laid in tile or cinder mortar: when we ſay that ſtones are to be laid in terraſs mortar, it is meant only round the facings, and the reſt is filled up with good common mortar; becauſe terraſs is very dear, as little is uſed as can be; I would adviſe the engineer, to lay all the facings with cinder or tile mortar, if he intends to make ſtrong work. For the mortar commonly uſed in facing the works, is generally ſo bad, that it requires to be new done in very few years; which is not only expenſive but likewiſe troubleſome.

The bricklayers and maſons content themſelves with making the facing look well; for which reaſon, when they build by contract they make uſe of mortar, with very little lime in it, that is, no more than to keep the ſand together; and when the wall is run up, they ſcrape a little out of the joints, which they point with a better ſort; ſo that the wall looks as well as if it had been built in the beſt manner. The only reaſon I can find, for their making worſe work here than any where elſe, is, that moſt people in and about *London* build upon leaſes, ſo that they contract with the bricklayer to do the work, never troubling themſelves whether it is well made or not; thinking if it but laſts their time it is ſufficient.

This is what the workmen are ſo uſed to, that when they are employed, by the publick, or government, it is with the greateſt care and conſtantly looking after them, to make them do better work.

The back part of walls, in ramparts and counterſcarps, ſhould be laid for the depth of about two feet, in ſtrong mortar, ſo as to dry ſoon; and the earth ſhould not be laid againſt them before a twelvemonth; for if the wall is not well dried beforehand, the continual dampneſs of the earth will prevent it from drying afterwards; and this is often the caſe, that walls cannot reſiſt the preſſure of earth againſt them, which they otherwiſe in all probability would have done, had the work been ſet before the earth was laid againſt them.

The manner of building arches, and other works under-ground, requires ſome particular precautions, beſides thoſe mentioned already, which we ſhall mention, when we come to treat of theſe kind of works.

Mr. *Belidor* ſays, that hard ſtones ſhould be laid in ſtiff mortar, and ſoft ones in ſoft mortar; which ſeems to me quite contrary to the nature of the thing: becauſe the pores of hard ſtones being very ſmall, and cloſe, the mortar cannot enter into them without being very ſoft and thin; on the contrary, ſoft ſtones, have larger pores, and are very ſpongy, and therefore require a greater ſubſtance to unite them; whereas thin mortar will ſoon be ſucked into the ſtones, without being able to unite them. This rule is obſerved by joiners, for when the wood is hard, they make uſe of thin glue, and on the contrary, in deal or other ſoft wood they uſe that which is thick and ſtrong.

The manner of building with bricks is much the ſame as that of building with ſtone; but it muſt be obſerved, that as bricks cannot be cut to the ſlope of the wall, and are always made ſquare; the bricklayers make the joints at the ſlope ſide bigger than within, in order to follow the propoſed profil, which is a very bad practice; for the weather beats the mortar out of theſe wide joints, by which the wall requires to be new pointed every two or three years; we have inſtances enough of this kind, not proper to be mentioned here.

Another defect ariſes from this practice, which is that the courſes of the bricks length being at right angles to the ſlope, and the reſt lie in a level, by which they make an angle, whereby the bricks can never bind ſo ſtrongly together, as if they were all laid in the ſame plan; whereas, if the outward ſlope be made one ſixth part of its height, and the courſes perpendicular to that ſlope, and to lie in the ſame plan, the bricks will bind much better together, and make a ſtronger work; as likewiſe reſiſt more the preſſure of the earth, as we have obſerved before.

I know that ſome engineers, and moſt workmen, ſay, that the courſes of ſtone or brick ſhould always be in a level, ſo as to bed well, otherwiſe, the wall will not ſupport itſelf upright; but this is no more than a conceit of the workmen, who will never go out of the old beaten road; for they do not conſider that the preſſure of earth endeavours to throw them forwards; and therefore, by oppoſing a greater force to this preſſure, the walls muſt laſt the longer; what they ſay may do very well in civil architecture, but by no means in the military way.

An engineer ſhould always conſider, what method anſwers beſt the propoſed deſign, and never follow the advice of others, unleſs it is agreeable to ſenſe and reaſon; for he that follows blindly the practice of thoſe that went before him, will never become a good engineer: This may chiefly be the cauſe of making ſo few improvements in fortification; for whoever reads authors that wrote upon the ſubject ſome hundred years ago, will be ſurprized, to ſee what few alterations have ſince been made, and theſe are, the moſt part, for the worſe.

Another great defect in brick-work, is the large joints made with bad mortar; they are commonly three quarters of an inch, whereas, half that thickneſs is more than ſufficient: A certain engineer piqued himſelf, to have all the courſes exactly three inches; and as the bricks are two inches and a quarter thick, the joints were three quarters; but this ought not to ſurprize any body, conſidering the humours of the perſon, which are altogether extraordinary, as well as moſt of his actions.

Sometimes bricks and ſtones are uſed together, eſpecially, in places where ſtone is ſcarce: This may be done to good purpoſes; for if the wall begins with ſtone to about ſix feet above ground, and then carried on as high with bricks, and over this, a bed of large ſtones is laid, then bricks as before, and another bed of ſtones; it will make better work than bricks alone; becauſe ſtone being heavier than bricks, they keep the work better together by their own weight.

When large ſtones are ſcarce, the facings of walls are made of bricks, and the reſt with ruble ſtones, but as it is hard to bind ſtones and bricks together, the work becomes very bad, unleſs great care is taken, to intermix them in a proper manner. The *French* engineers make the bricks go off from the facing towards the back part of the wall, in an edge, or like an inclined plan, and fill the reſt with ſtones; this may be done in another way, by carrying here and there a courſe of bricks quite croſs the wall, of three feet broad, and two high, at proper diſtances from each other, which will bind the wall pretty well together. In ſhort, the engineer ought to judge from the materials, and his own experience, what is beſt to be done upon all occaſions.

SECT. IX.

Of CAZEMATS *and all ſorts of under-ground* WORKS.

THE method of building the walls of under-ground works, requires much more precaution, than thoſe that are above, not only becauſe they are to be bomb-proof, but likewiſe to keep out the damp or wet, that whatever may be depoſited in them, as men, ammunition, and proviſion in time of a ſiege, may keep dry, and be preſerved without any damage.

In ſmall fortreſſes, there cannot be too many under-ground lodgments, becauſe nothing can be ſecure otherwiſe; ſince the ſhots and ſhells can reach every part of the place, and deſtroy it: Therefore there ſhould not only be a ſufficient number of magazines that are neceſſary to lodge ſtores and ammunition, but likewiſe hoſpitals for the ſick and wounded, and places to reſt the fatigued ſoldiers, in a ſecure manner. Whereas, in large places, there is always ſome part or other which are ſecure from ſhells or ſhot, which may ſerve to lodge every thing that is not immediately wanted.

But before we enter into the particulars of their conſtructions and ſituations; it is neceſſary to explain the manner of building them.

As we have but few works of this kind here, and moſt of them were built by ſuch engineers as were not ſkilled in them; we ſhall inſert the method purſued by the *French*, given by Mr. *Belidor* in his *Science des engineers*; as knowing that he had it from the moſt knowing and experienced engineers of *France*.

We ſuppoſe, ſays he, that the maſonry has been built with all poſſible precautions, that is, the ſtone or bricks to have been laid in mortar made of the beſt lime to be had, mixt with tile or cinder duſt, and left to dry a ſufficient ſpace of time before it is covered with a particular kind of cement, made according to the following manner.

This cement is generally made of tourneys cinders, which is nothing elſe but the cinders, that are found in lime kilns, where they uſe coals, mixt with the ſmall particles of lime ſtone: this is beat and prepared every four or five days, for the ſpace of ſix weeks; obſerving to put only a ſmall quantity of water to it the firſt time, and none afterwards; or this cement is made with mixing one third of unſlaked lime, the beſt that can be had, with two thirds of terraſs, or inſtead of terraſs, two thirds of pozolano, or elſe old tiles well burnt, reduced into duſt, and paſſed through a ſieve: but whether the one or the other of theſe cements be uſed, the parts muſt be well reduced into duſt ſeparately, with a hand mill, and afterwards the two materials well beat and mixed together, and to repeat this ſeveral times without any water, excepting at firſt.

Before the cement is applied to the vaults, it is neceſſary that the maſonry be well finiſhed, and had a

ſufficient

ſufficient time to dry, which is reckoned to be about ſix months; then the joints muſt be well cleaned with a ſmall iron hook, after that the duſt and dirt being ſwept off very clean, ſome water is ſprinkled over it with a water-pot; then the cement is laid over it, being well worked immediately before, of about an inch and a half thick every where, and as even as can be; which is beat all manner of ways with a wooden battle, of two inches broad only, in order to preſs the cement better into the joints; after that, it is made quite ſmooth with a flat iron, ſuch as are uſed for ironing linen, till it begins to be hard; and for ſome time it muſt be rubbed over with a mop dipt into cement made very thin, once every day, and then paſſed immediately over it with the aforeſaid iron, to make it ſmooth; and when this is done, it is covered with ſtraw, to prevent the heat from cracking it; this work is continued till ſuch time that no cracks appear in it: after that it is waſhed over for five or ſix days as before, without poliſhing or coverings.

In applying the cement, care muſt be taken, above all things, to make it ſmooth and even, and to terminate the upper part in an angle like a roof; and ſo as no ſtone appears through the cement. This being done, the cement is covered with a bed of gravel or coarſe ſand of four or five inches thick, laid every where very ſmooth and even; and upon this bed of gravel is laid another of earth of about a foot and a half thick, well beat and rammed down; and then more earth is put upon it, and beat down; this is continued quite up to the ſurface of the ground: Mr. *Belidor* ſays, that the vaults in the lower-baſtions of *New Briſac* were built in this manner.

I ſhould think, that if a bed of well prepared clay of about ſix inches deep, was laid over that of the gravel, and over that one of earth, it would much better prevent the water to penetrate to the cement, than earth only; as to the gravel, its uſe is to ſuck in the dampneſs of the ground above it, and to keep the moiſture from the cement.

Mr. *Belidor* propoſes another method, which, he ſays, has been uſed in the building of a famous orangery at *Verſailles*, with great ſucceſs, and which is as follows.

As ſoon as the vault was made, it was well cleaned, and a bed of ruble ſtone laid over it, of 18 inches thick, without any mortar, only duſt of lime thrown between the joints; upon which was laid a bed of the ſame duſt four inches thick; and then a bed of pebble ſtone, and then another of flat ſtone of a foot deep; which was covered with another bed of lime duſt of four inches thick: this, he ſays, was continued to the very top, and even with the level of the terraſs above it: This vault has ſtood hitherto the weather, without the leaſt change or alteration.

The ſame author ſays, that ſometimes, a bed of clay a foot thick has been laid over the firſt bed of ſtone, and one of mortar three or four inches thick over the laſt, and then the earth. To ſecure the piers of underground vaults againſt the water filtering through the earth, a wall of dry ſtone is made againſt them on the outſide, of two feet thick, without mortar, the joints being filled with gravel or coarſe ſand; and the wall is continued to within two feet of the roof of the vault; the reſt being finiſhed with good maſonry, and covered with the bed of cement, which lays on the vault, and is extended over the wall: this precaution will ſecure the piers from all dampneſs; but it ought to be obſerved, that this dry wall ſhould be two feet lower than the foundation of the vault, in order to make a gutter for carrying the water into the ditch.

rizontal courſes, as high as the ſpring of the arch; and the arch itſelf, perpendicular to the ſlope, in the manner repreſented by the third figure: there are two folding doors, one at the entrance, and the other at the going out, that they may leave a free paſſage for guns and other warlike engines, and ſometimes ſeveral of theſe doors are made, in order to defend the paſſage; for which purpoſe, wickets and loop-holes are made in them, to retire through and defend them one after another.

The walls are about two feet and a half near the foundation, with a ſlope on the outſide, ſo as to be two feet only near the ſpring of the arch, and the arch itſelf is but two feet without any counterforts; becauſe the weight of the arch is ſufficient to counterbalance the preſſure of the earth. The magazines on both ſides of this paſſage, are 14 feet ſquare, and the walls are half a foot ſtronger than the others. The top of the arches of both the paſſage and the magazines, are covered with a cruſt of cement, and above this with dry ſtones, as well as the ſide-walls, in the ſame manner as has been mentioned before.

In fortreſſes where a river paſſes through the ditch, ſuch a paſſage as the laſt is made to water the horſes; which are ſometimes walled up in time of peace, and at others left open, with a ſtrong gate to lock them up at night; but as they are the ſame as the former, we ſhall ſay no more about them. As to the foundations and many other particulars relating to theſe paſſages, we ſhall leave them to the judgment of the engineer, who is to conſider well beforehand all the conveniencies, and every minute circumſtance, before he begins the work.

It is cuſtomary to build hoſpitals for the ſick and wounded, under the level ground of the baſtions, as likewiſe powder-magazines, ſtore-houſes, and ovens to bake the bread; theſe buildings conſiſt of a long paſſage from the center of the gorge towards the ſaliant

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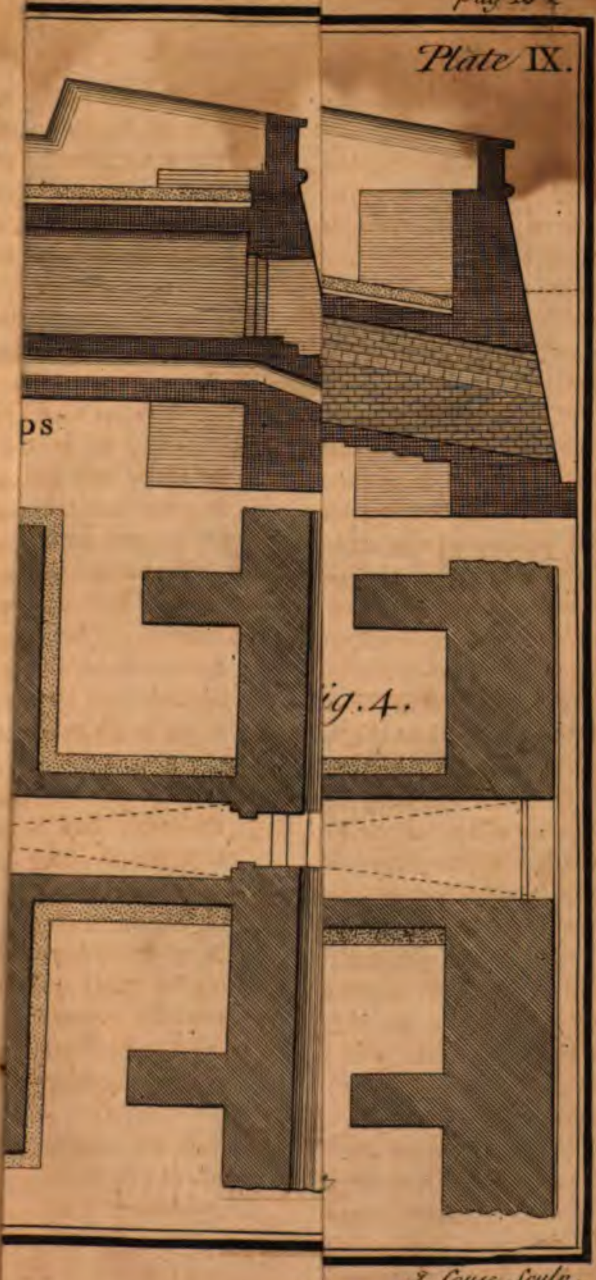
Plate IX.



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ant angle, with as many rooms on both ſides as are thought neceſſary; ſome of them have chimnies, and others air-holes coming out within the baſtion; theſe buildings are eſpecially made when there is a cavalier in the baſtion; becauſe they need not then be ſunk under the level, there being always a ſufficient quantity of earth above them, to reſiſt the force of the ſhells. Theſe works are built in the ſame manner, and with the ſame precautions, as the former.

SECT. XI.

Of CASEMATS *in the* RAVELIN.

AS we eſteem the ravelins to be the moſt eſſential of all the outworks of a fortreſs, ſo we think that nothing contributes ſo much to a long and ſtout defence, as the making them capable of all the reſiſtance that is poſſible: For a town defended as it ought to be, can never be taken, till ſuch time the enemy is maſter of the ravelin in the front attacked. *Coehorn* and ſome others, have made their ravelins with caſemated flanks, but for what reaſon is unknown to me; though ſeveral pretended engineers look upon them as conſiderable works: It is therefore worth our while to examine their uſe and perfection, in order that young engineers may not be miſled by the erroneous opinions of their ſuperiors.

As theſe flanks cannot defend the ravelin, in which they are, their intent muſt neceſſarily be to defend ſome other work: which can only be the breach in the faces of the baſtions oppoſite to them; the paſſage of the great ditch, or the covert-way: But as the ravelin in the front attacked, is either taken, or its defence deſtroyed by ſhells, and the ricochet batteries; before theſe works are or ought to be attacked, it is evident, that theſe flanks in the front attacked, can be of no uſe at all. Neither can thoſe of the ravelins in the fronts, adjacent to that attacked, be of any uſe, ſince but a few of the guns placed there will bear upon the the attack; and the beſiegers have always ricochet batteries to deſtroy the defences of theſe works, which ſee the attack, as may be ſeen in the ſixth plate of our attack; beſides, the ſame batteries which batter the breach in the baſtions, will ſee obliquely theſe flanks; or the moſt trouble theſe flanks can cauſe, is to oblige the beſiegers to raiſe two batteries of four guns each, in order to deſtroy them. I leave it therefore to the judgment of the reader, whether it is worth while to make theſe expenſive works, for ſo little a purpoſe, or whether ſome others might not be made of a much better defence, and of no more expence than theſe.

Notwithſtanding that the ravelin in the front attacked at *Bergen-op-zoom*, had caſemated flanks, yet the *French* took both baſtions, and ravelin at the ſame time, without given the beſieged time to fire a gun from them: this was not ſo much owing to the bad conſtruction of the works, as to the unſkilfulneſs of the defenders, or to ſomething elſe not proper to be made public.

Plate X. The beſt way to ſecure the ravelins, when the ditches are dry, in my opinion, is to make redoubts in them, with a parapet of about 12 or 15 feet thick only, and about two feet lower than that of the ravelin; that thickneſs is ſufficient, ſince it can only be ſeen from the rampart of the ravelin: and if the counterſcarp be caſemated in the manner marked with dotted lines in the plan, Fig. 1; and as the plan of the works ſhews in the ſecond figure; it appears to me a difficult matter for an enemy to get poſſeſſion of it.

That there may be a ſecure communication from the works in the redoubt to thoſe in the ravelin, and from thence to the covert-way; traverſes are made in the ditches, marked L, L, in figure. 1. or *l*, *l*; in the ſection, fig. 3: Theſe caſemats have two entrances, marked E, E, in fig. 2, from the ditch or the caponier uſually made from the oppoſite curtain to the gorge of the ravelin; as well as two ſtair-caſes, marked D, D, in the ſame figure, to mount into the redoubt, as likewiſe two more in the level ground of the ravelin, not marked here; ſo that if the enemy gets poſſeſſion of one ſide of the ravelin, the garriſon may ſally out through the other; or when the redoubt is loſt as well as the under-ground work on one ſide, they may retire through the other.

As the beſiegers can no other ways get poſſeſſion of theſe works, than by mines; openings muſt be left in the great gallery A, A, at proper diſtances, for counter mines to be carried on all the way under the ramparts, and behind the parapets, to reſiſt the enemies miners; as likewiſe to oppoſe every attempt they can make, both above and under-ground, in ſuch a manner, as to make it equally hazardous wherever they may chooſe to aſſail the work.

The openings of theſe galleries into the ditches of the ravelin and redoubt muſt be well ſecured with ſtrong doors, full of iron, and behind theſe others with wickets and loop-holes, to retire behind, and to defend the entrance that way, in caſe the enemy ſhould attempt it; as probably he would if they were not well ſecured.

The walls of theſe under-ground works need only be about two feet thick near the foundation, with a ſlope on the outſide, ſo as to become a foot and a half near the ſpring of the arches; this will be ſufficient, becauſe the arches will ſecure them againſt the preſſure of the earth. The piers which ſeparate the lodgments B, are not ſo much made to ſtrengthen the wall, as to prevent the arches from being too high, which may be elliptical or parts of circles. Theſe lodgments are 10 feet wide, that is, as much as the great gallery is broad, in order that the arches may join well; and the baſe of the piers are 8 feet long; ſo that the whole breadth of the great gallery and the lodgment together is 18 feet.

The bottom of this gallery muſt be about 18 inches above the bottom of the ditch, in order to ſecure it from dampneſs, and the piers are 7 feet high, with loop-holes between them, which look into the ditch, to give air to the lodgments: as to the reſt, the plans and ſection ſufficiently ſhew our meaning, without being neceſſary to enter into any farther explanation: The only thing to be farther obſerved, is, that the arches at the entrance E, and over the ſtair-caſes D, muſt be made conical; as to the others, the reader may eaſily perceive how they ought to join.

Mr. *Coehorn* made ſuch galleries all round his counterſcarp at *Bergen-op-zoom*, with loop-holes to fire into the ditch, and at the reentring angles of the places of arms, lodgments nearly ſuch as are marked here, which he called *Tambours:* and to ſecure the entrance above ground, he made a traverſe on each ſide of the ſtairs, as likewiſe placed a row of paliſades. As theſe lodgments made the beſt defence of all his works, in the laſt ſiege; it is plain that they are very advantageous in a fortreſs; but as to the gallery round the counterſcarp, it was of no other uſe than to lodge the troops ſecurely from danger, and to carry from thence galleries for mines under the covert-way and glacis. For which reaſon, I would either chooſe to make none, or one of about 6 or 8 feet wide, which would ſufficiently anſwer the intent propoſed; and beſides, would coſt very little more than a ſingle wall with counterforts: there might be ſome wooden doors placed at proper diſtances, with loop-holes, ſo that if one part was taken by the enemy, the defenders may retire ſecurely into the others.

As to the caſemats under the places of arms, they ought by no means be neglected, and to ſecure their entrance above, there ſhould ſmall redoubts be made of 12 or 15 feet parapet, and a dry ditch before them; by this means the places of arms may keep off an enemy a long while, and make them pay dear if they take it; as it happened to the *French* at *Bergen-op-zoom*.

It may be obſerved in general, that a fortreſs without under-ground works, can make but a ſmall defence now-a-day, againſt the great quantity of artillery with which armies are furniſhed at preſent; for the defences above ground are ſoon deſtroyed thereby: therefore an engineer who undertakes to fortify a place, muſt make uſe of all his ſkill and knowledge, to conſtruct ſuch under-ground works, as are beſt adapted to the nature of the ſituation; and to be as ſaving as poſſible, becauſe theſe kind of works are naturally very expenſive.

SECT. XII.

Of CASEMATED FLANKS.

Plate XI. MESS. *Coehorn* and *Vauban*, were very fond of caſemated flanks, the former made ſome in the ravelins at *Bergen-op-zoom*, and the latter in his tower baſtions at *New Briſack*; they have been in great eſteem formerly by moſt engineers, and a fortreſs without them was not thought to be of any ſtrength; but now-a-days they are generally rejected, becauſe experience has ſhewn, that the ſmoak becomes ſoon ſo troubleſome as nobody can bear it, notwithſtanding all the chimnies and air-holes that can be made to prevent it.

As the only objection againſt theſe caſemated flanks, is their ſmoaking, engineers have endeavoured to find ſome remedy or other for it: but that propoſed by Mr. *Belidor*, ſeems, in my opinion, to be the beſt, and is what has been practiſed in ſeveral places, as I am told, and have ſeen myſelf at *Portſmouth*, near the ſea; which

SECT. XIII.

Of CAPONIERS.

A CAPONIER is nothing elſe but a paſſage made in a dry ditch from one work to another; when they are made from the curtain of the body of the place to the oppoſite ravelin, or from the front of a horn or crown-work, they have a parapet on each ſide of ſeven feet high, ſloping in a glacis on the outſide to the bottom of the ditch; the width within is from 15 to 18 feet, with a banket on each ſide: there is a brick wall to ſupport the earth within, of a brick and half above, with a ſlope of a fifth part of the height; this wall reaches only within a foot and a half to the top; to prevent graſing ſhot, from driving the ſplinters amongſt the defenders. Theſe caponiers with two parapets may properly be called double; for there are ſome made with one parapet only, in dry ditches of the ravelin, and in that of its redoubt, towards the ſailant angles, and open towards the body of the place; it is true, that theſe ſingle ones are alſo called traverſes, but differ from the traverſes in the covert-way, by their tops ſloping in a glacis to the bottom of the ditch, whereas the others are made in the form of all other parapets.

Caponiers made from the body of the place to the outworks, are ſometimes arched over, with loop-holes to fire into the ditch; they have likewiſe doors on both ſides for a communication from them into the ditch; becauſe the beſiegers never fail to deſtroy them by ſhot and ſhells, to render the paſſage more dangerous. The ſingle ones in the ditch of the ravelin and redoubt, are likewiſe made with arches open towards the place, ſuch as we have ſpoken of here before; by making them in this manner, the guns which defend the ditch

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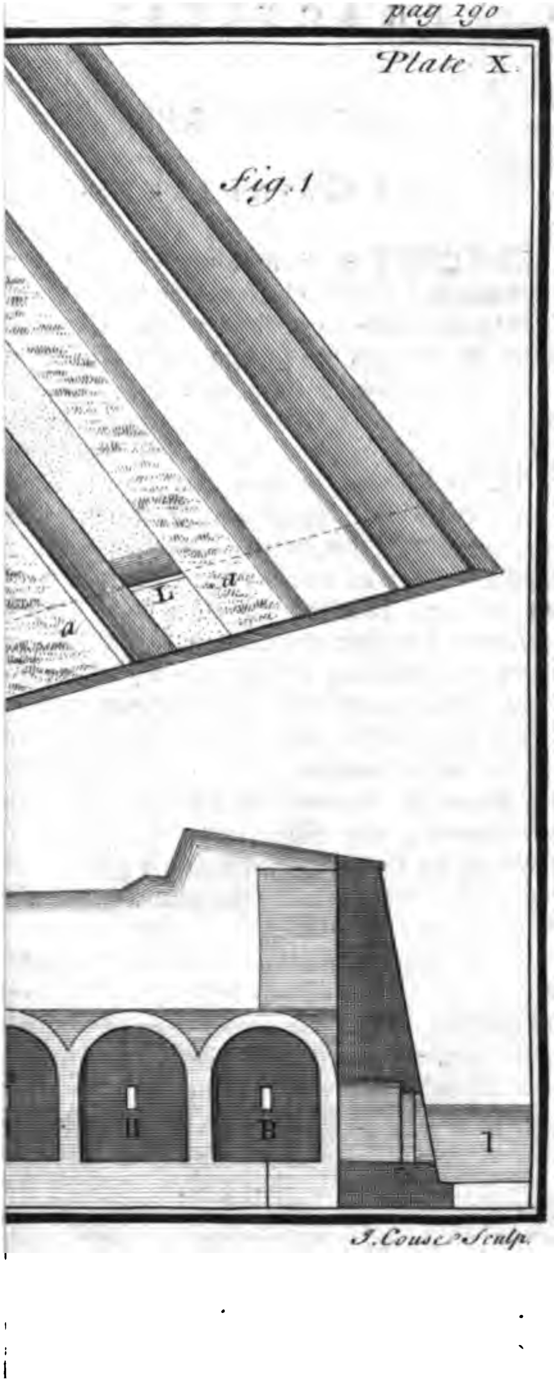
Plate X.



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before them can no other ways be diſmounted than by mines, and when they are ſo low as that no mines can be made under them, the enemies paſſage over theſe ditches becomes very dangerous.

To make the paſſages or communications from one work to another, ſo as not to be interrupted in time of a ſiege, or deſtroyed, is the moſt difficult part of fortification; for when the retreat out of a work is cut off or made dangerous, the troops in them neither will nor can defend them with ſo much courage and bravery as they would do otherwiſe; and this is the reaſon that an enemy always endeavours to deſtroy them; and ſhould likewiſe engage engineers to prevent it.

SECT. XIV.

Of TOWN-GATES *and* GUARD-HOUSES.

THESE gates are made various ways, ſometimes there is only an open paſſage cut in the rampart, ſhut up by a ſtrong wooden gate, or with a draw-bridge; and at others, this paſſage is arched all over, with a guard-houſe within, and a draw-bridge, and a gate on the outſide; the outſide front is generally ornamented with pilaſters and a pediment; the decoration chiefly depends on the taſte the engineer has in architecture.

As we have no author that has wrote on military architecture, nor any of our fortreſſes, that I have ſeen, has any works of this kind worth mentioning; I was obliged to have recourſe to Mr. *Belidor's Science des Ingenieurs*, which is the only work that treats of theſe things, in the modern taſte; for what is to be found in *Dilichius*, *Spekel*, and other old *German* authors, is of ſo groteſque a taſte, as ſcarcely would be followed now-a-days. But as the *French* are ſo magnificent in their military buildings, and the deſigns of this author are chiefly adapted to large fortreſſes, which are not in uſe, nor neceſſary in this country; we have endeavoured to make ours in ſuch a manner as will moſt probably be of uſe to our engineers.

Plate XI. Our firſt deſign in this plate is quite plain; the width of the paſſage is ten feet, and arched above; at the entrance within is a guard-room for the ſoldiers on one ſide, and one for the officers on the other; each of theſe rooms is twelve feet ſquare, having a window in the front, two feet and a half from the ground, three feet wide, and ſix high; for it is a general cuſtom in all buildings to make the windows on the ground floor twice as high as they are broad; the cheminies are four feet wide, and a foot deep, half of which is taken out of the thickneſs of the wall, and the other projects into the room, and is ſupported by piers of a foot thick: the doors are three feet wide and ſeven high.

The walls of the paſſage which ſupport the arch, are eight feet high, three feet thick near the foundation, with a ſlope on the outſide, ſo as to be two feet and a half at the ſpring of the arch, which is alſo the thickneſs of the arch itſelf; the walls of the guard-room are two feet thick only, and the height of the elevation from the bottom to the roof is fifteen feet.

I have made no counterforts to theſe walls, becauſe the preſſure of the earth, together with the ſtrength of the wall, will be ſufficient to reſiſt the preſſure of the arch. This arch, as well as all thoſe mentioned hereafter, muſt be covered with a bed of cement and dry ſtones over them, as has been mentioned before, where we have treated of this ſubject.

The outſide of this paſſage, that is next to the ditch, is ſhut by a ſtrong wooden gate covered with iron bars and rails, ſo as not to be cut open by any tools; and if it be thought neceſſary, a draw-bridge may be made; but as this gate is deſigned for a ſmall fort only, there is no occaſion of making any ornaments that require much

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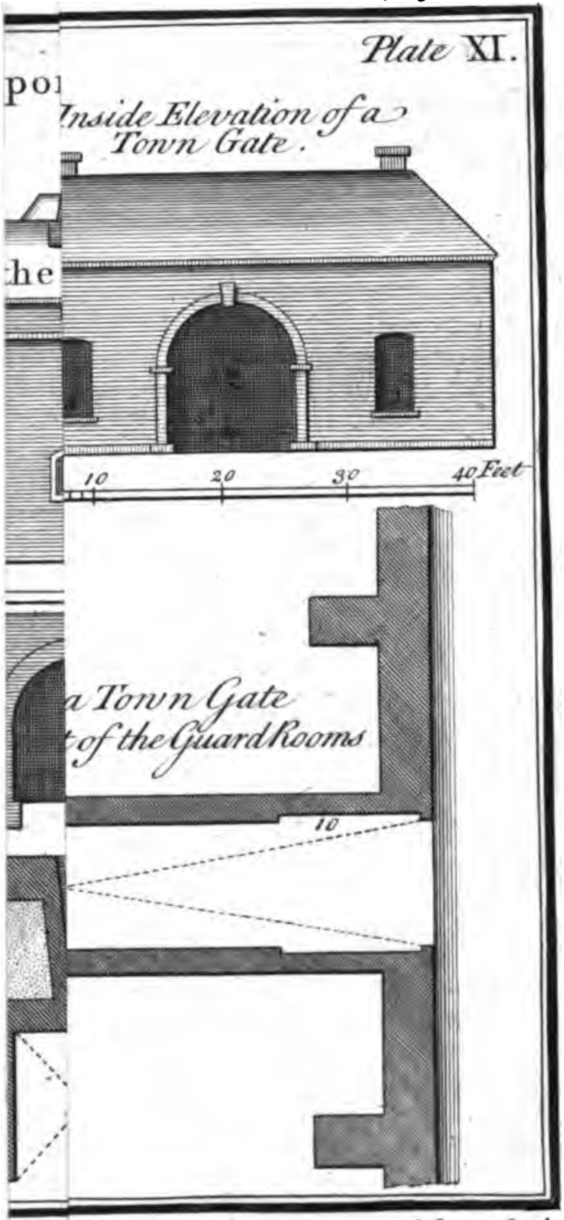
Plate XI.



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much expences; for which reaſon, a plain wall with a pediment will be ſufficient.

Plate XII. As the outſides of gates are made various ways, and thoſe in ravelins, horn or crown-works, are different from thoſe of the body of the place, becauſe the paſſages are not arched, but always left open above; we have given here three different ſorts; the firſt is quite plain, and may ſerve for any outwork: it is compoſed of two piers of 24 feet high and 7 broad, with a baſe of two feet high, having a corniſh and round balls above; the opening in this and the two following ones, is 10 feet: The firſt figure repreſents the elevation, and the ſecond the ground plan, with the ſlopes and projections; there is a draw-bridge to this gate, the ſection of which is repreſented in the elevation.

The third figure repreſents likewiſe the elevation of a gate in an outwork, made in a more expenſive manner than the former: For the two piers are of hewn ſtones, ten feet broad, and 27 high; each of them is ornamented with two pilaſters, made according to the *Tuſcan* order; that is, the height is ſix times their breadth, the plinth or baſe is half the breadth high; as is likewiſe the torus or moulding next to it, with the fillet: And if we ſuppoſe the breadth of the pilaſter to be divided into 24 equal parts; the aſtragal and fillet is one and a half of theſe parts, the gorge 4, the next fillet one, the quart de rond 3, the abacus 3; and the laſt fillet one; the entablement is 30 of theſe parts: The fourth figure repreſents the ground plan, with the ſlopes and projections.

The third gate repreſented by the fifth figure, is deſigned for the body of the place, when the paſſage is arched; the width of the gate is 10 feet, the height from the bottom to the ſpring of the arch is 8, but may be from 8 to 10 or 12; the diſtance from one wall to the other 14, and their height including the corniſh 30, and 12 broad; as to the pilaſters, pediment and mouldings, they are the ſame as before, and the pediment is from one third to two ninth parts of its baſe high : The pediment ought to be ornamented either with the king's arms, or with military enſigns, and above the gate under the arch, which joins the piers, the arms of the city, or elſe, of ſome particular perſon of note, who has moſtly contributed to the building of the place.

Theſe are only a few ſpecimens of gates, to give the young practitioners an idea of theſe kinds of work; the proportion of the parts may vary as well as the ornaments; but when there are pilaſters or columns, they muſt be conſtructed according to the dimenſions of the order, they are made of: We have made uſe of the *Tuſcane* order as being the moſt ſimple; but a young engineer ought not to content himſelf with what has here been given, but apply himſelf to that part of architecture, which is moſt uſeful; and if he wants gates of a finer taſte, he may conſult Mr. *Belidor's Science des Ingenieurs*, where he will find a great variety and well choſen examples.

Gates of large fortreſſes, require more attention, than thoſe of ſmall ones ; they muſt not only be ſecured with draw-bridges, but with port-culiſſes, harrows, or organs. A port-culiſs, is a wooden gate well covered with iron, with ſharp points, drawn up in day-time by pullies, and let down at night: A harrow is a gate made of timber, whoſe dimenſions are commonly 6 by 4 inches; and 6 inches diſtant from each other, well faſtened to three or four croſs-bars, and ſecured with iron: And an organ, is a wooden frame, with double bars, through which the timbers ſlide and fal down: the organ differs from the harrow in that th timbers are not faſtened together, and is often prefer red to the harrow on that account; becauſe it is ſaid that if an enemy cuts one timber to pieces another ma immediately be let down, which cannot be done in th harrow.

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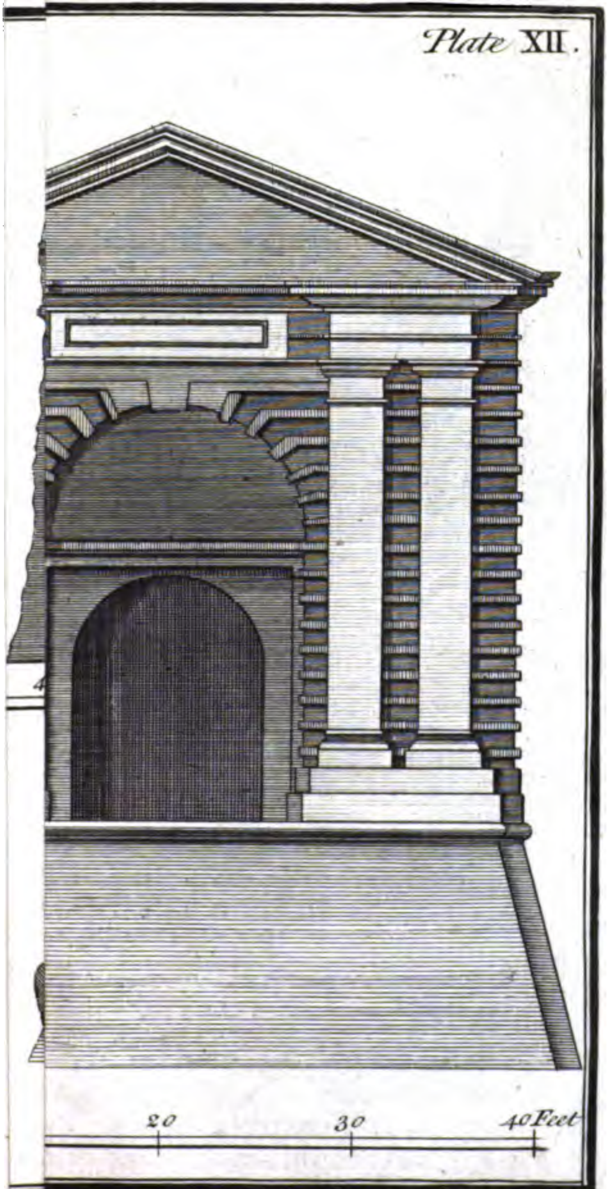
Plate XII.



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The port-culiſs, harrow, and organ, ſerve all for the ſame purpoſe; that is, to ſtop an enemy in caſe he has found means to let down the draw-bridge; either the one or the other may be uſed as the engineers think proper, and ſometimes two of them, that if one has been cut or burnt, the other may ſerve to ſtop the enemy.

But to leave nothing which may give a clear idea to beginners, we ſhall give ſome deſigns of theſe gates when we come to treat of draw-bridges, barriers and other things of that kind.

Plate XIII. As we have given one example only of a town-gate, which is very plain and ſimple, we ſhall preſent the reader with another, that may ſerve for the body of the place, which, though plain, yet is, in my opinion, ſufficiently ornamented; it is compoſed of an arched paſſage and two piazzas at the entrance, for the conveniency of foot paſſengers, to get by carriages that enter or go out; at the left ſide of the entrance is the guard-room for the ſoldiers, and at the right the room for the officers, and as this laſt need not be ſo large as the former, a priſon is made, ſo as to make both ſides of the paſſage alike: above theſe rooms, and over the gate, are lodging-rooms, for the town major, and ſome other officers.

The paſſage is ten feet wide, and the projections to form the cavity for the port-culiſs, as well as thoſe on both ends, are ſix inches; the thickneſs of the walls or piers which ſupport the arch is four feet near the foundation reduced to three above near the ſpring of the arch, and are 8 feet 6 inches high, and the arch is hree feet thick. The length of this paſſage, and that f the former depends on the thickneſs of the rampart, or which reaſon, they are not determined; the piazas at the entrance are 9 feet wide, and 12 deep; the iers which ſupport the arches 5 feet each way; the uard-room for the ſoldiers is 20 feet long, and 14 eep, with two windows of 2 and a half or 3 feet wide, and as high again; the chimney 4 or 5, and the door 3 by 7: The officers room is 10 ½ feet long, and 14 deep, and the priſon 8 by 14; the walls of theſe rooms are 27 inches or three bricks thick; the wall between the officers room and the priſon is a brick and a half only, and the chimneys 4 feet wide; as to the windows and doors they are the ſame as the others.

As this building is too large to make it but one ſtory high, it was for this reaſon we contrived the above mentioned lodging rooms above it: the elevation here is that of the inſide or entrance, in which we could not repreſent the chimneys for want of room in the plate: The fifth figure of the laſt plate is the elevation of the outſide next to the ditch; to this front is annexed another building, the lower part of which ſerves for the baſcul of the draw-bridge, and the upper, to receive the port-culiſs: The ſection through the length of the paſſage ſhews partly the nature of the building, whoſe breadth is equal to that of the paſſage and walls.

As the inſide and outſide buildings do not join above, there is a paſſage left between them for a free communication upon the rampart, from one ſide to the other; that part of the arch is covered with a bed of cement, and dry ſtones over it, with three feet of earth beſides. In this ſection is alſo ſeen the ſide of the wooden frame *ab*, called *baſcul* by the *French*, which is fixed to the draw-bridge, by one end *b*, with a chain at each ſide, each paſſing over two pullies or rollers, turning upon an axis at the other end *a*, and is a kind of counterpoiſe to the draw-bridge, to raiſe and let it down by; the particulars of which ſhall be explained hereafter, where we treat of draw-bridges.

There are ſtone ſteps made at the ſides of the inſide building to mount upon the rampart, which are not marked here in the plan, but are neceſſary, becauſe there is always a ſentry placed there at night; beſides, when there is an alarm, that the guard may mount quickly, and without any obſtruction.

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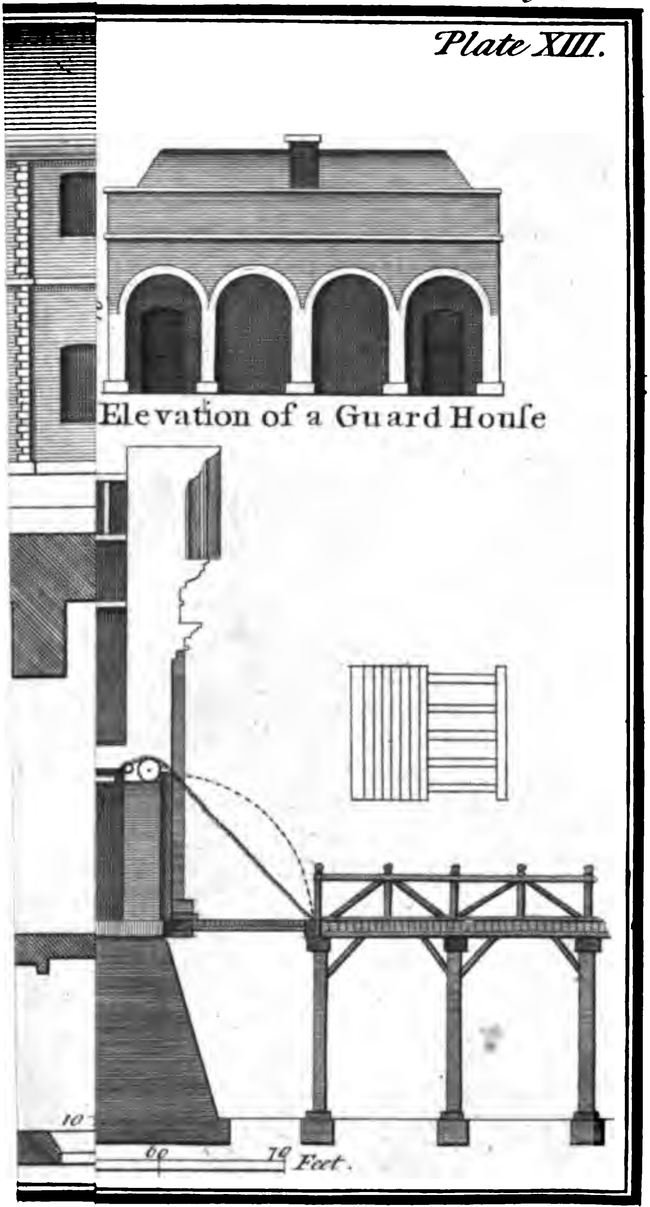
Plate XIII.


Elevation of a Guard Houſe

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At the entrance of a fortreſs, and in the works that cover the gate, ſuch as ravelins, horn or crown-works, are guard-rooms built, for the party without the inner gate, and which are ſhut out at night by the draw-bridge in the curtain of the body of the place: Theſe buildings conſiſt of two rooms, one for the officer, and the other for private men, as the plan and elevation in this plate ſhews.

The officers room is 12 by 12 feet, and that of the private men 12 by 15; and there is a piazza of four arches before it, of 6 feet broad, and as long as the building, for the ſentry to walk under in hot and rainy weather; the arches are ſupported by five piers or pillars of about 15 inches ſquare, and at 6 feet diſtant from each other; the wall is two feet thick, the windows 3 wide, and as high again; the chimneys 4 feet wide, and the doors 3 by 7; the elevation is about 16 feet high, including the parapet wall of the roof: The piazza may be made arched or flat roofed, according as it is thought proper by the engineer,

SECT. XV.

Of BRIDGES.

Plate XIV. THE next works in order are the bridges of different kinds, ſuch as draw-bridges, turning-bridges, ſtone or wooden immoveable bridges; as the draw-bridges are immediately joined, and make a part of the town-gates, we ſhall enter firſt into their conſtruction.

They are generally ten feet wide, and twelve long; and are compoſed of the trunion-beam *a*, head-beam *b*, and ſix joiſts C, covered with two inch planks, *d*: The trunion-beam is 12 inches broad, and 10 thick; the head-beam 10 broad, and 8 thick, and the joiſts are five by ſix, tenanted into the trunion and head-

beam;

beam; as theſe planks would ſoon wear out by the carriages that continually paſs over them, they are covered with iron barrs of ſeven feet long, and about three inches broad, one over each joint, and one upon the middle of the plank; their number is generally 32; each of theſe bars is faſtened with four cramps, which are not repreſented here; the joiſts are likewiſe faſtened underneath to the trunion and head-beams with iron plates each about 3 feet long: the trunions are about ſix inches long, three in diameter; faſtened to the trunion-beam with two plates, one above and the other below; bolted and rivetted together; the rings or handles of the chains are joined to the head-beam much in the ſame manner as the trunions.

Draw-bridges are drawn up and let down, by various contrivances; the moſt common way is, by a wooden frame, ſuch as is joined to the draw-bridge in the third figure; it may be obſerved, that the ſide beams G K, H N, go tapering from the trunions E, F, towards the ends K, N, in order to make the frame E G H F, nearly of the ſame weight as the draw-bridge: It turns round the trunions E, F, upon iron plates, and the frame G H, moves in a cellar under the gate-way, built for that purpoſe; there are two holes one on each ſide, to thruſt two long poles through upon the ends G, H, to preſs them down, and raiſe the draw-bridge, as likewiſe, two chains are fixed to theſe ends, paſſing through the ſame holes with a large ring at the end of each, whereby the baſcul is drawn up, and the draw-bridge let down. This method can only be uſed when the ditch is dry; for when it is wet, the cellar is apt to fill with water, notwithſtanding all the care that can be taken in the building of it; whereby the wood will rot in a ſhort time, and the draw-bridge in danger of not being drawn up when it is required; beſides, the making this cellar in a proper manner, ſo as to be water tight, will be very expenſive.

Another method of drawing up draw-bridges, and which is often practiſed, is to make the baſcul ſeparate, and not joined to the bridge; ſuch as is repreſented by the ſecond figure: This frame is fixed by the trunions at L, P, over the gate-way, and two chains fixed on the other ends M, Q, go each over two pullies or rather rollers, and are faſtened with the other ends to the head B, D, of the draw-bridge B C, figure 1; ſo that when the part M Q, is drawn down by chains faſtened to them for that purpoſe, the draw-bridge raiſes. This method has the advantage, that in caſe the enemy ſhould find means to break the chains which faſten the draw-bridge to the frame; and thereby make it fall down; the frame M P, will alſo fall down and ſtop the paſſage, and it will not be in his power to raiſe it: But in caſe any thing ſhould happen to the chains, an opening W is left in the middle of the frame, to paſs through it, and this opening may be ſhut up by a wicket, that is to be lockt upon occaſion. We have ſuppoſed this method to be uſed in the gate-way, repreſented in the thirteenth plate, where the ſide view of the beam P Q is ſeen in the third figure, as well as one of the chains with its rollers.

It muſt be obſerved, that the head M Q of the frame muſt be well loaded with timber, in order to bring the frame nearly in equilibrio with the draw-bridge; which is not ſo eaſily done as one might imagine; and experience has ſhewn, that many engineers have miſcarried in their deſign: and when this does not happen, the draw-bridge cannot be let down nor drawn up, without very great difficulty.

The only way of doing this, is to have timbers or any other weights, fixed near the piece M Q, ſo as to ſlip off and on, and when both the bridge and frame are fixed, to try how much weight will do.

Plate XV. Another way of fixing draw-bridges, is, a baſcul with wings, ſuch as is repreſented by the fourth figure, which is fixed over the gate-way, upon

the two trunions E, F, and the chains are faſtened to the ends of the wings; and two leſſer ones to the ends A, C, of about eight feet long, with a ring of 8 or 10 inches diameter, in order to draw down the hind part of the baſcul, and thereby raiſe the bridge; and the bridge is let down, by raiſing up the hind part A C to the height of 5 or 6 feet, and then with poles they puſh it up higher, whilſt others get upon the bridge to bring it down by their own weight.

When the bridge is down, two bolts fixed to it are puſhed into two ſtaples, drove into the fixed bridge; and to guard the ſides of the bridge, that nothing may fall over; there are two ſtrong chains faſtened with one end to the wall, and the other to the poſt of the immoveable bridge, about four feet above the draw-bridge.

It is eaſily perceived, that the baſcul E C, muſt be of ſuch a weight as that the bridge may be drawn up with a ſmall force; for which reaſon, the frame is loaded with timber towards the hind part A C, in the manner repreſented here, in this figure; and it happens ſometimes, that they are obliged to faſten ſhells or any other heavy weight at the ends A, C, to bring the weight of the baſcul nearly equal to that of the draw-bridge.

This method of fixing draw-bridges has been in uſe a long while, and has been practiſed more than any other; but when it is uſed in the draw-bridge of the body of the place; the cavities cut into the front of the building to receive the wings, disfigure the ornaments of that front very much; and another inconveniency it has, is, that every time the bridge is raiſed, it requires a great force at firſt to move it; this motion accelerates afterwards more and more, till at laſt it becomes ſo great, that it ſhakes the building very much.

But when draw-bridges are made to the outworks, or ſometimes on the middle of a fixed bridge, this method is always uſed; then the baſcul A D is ſupported ed by a wooden frame, of about 12 feet high, upon which the trunions E, F, turn: It is true, that when the bridge is drawn up, the wings are upright, and exceed the height of the bridge, by about 12 feet, which the beſiegers endeavour to break by firing at them, and if they accompliſh their deſign, the draw-bridge falls down, whereby the paſſage is left open: But as no other method has yet been found, that anſwers the purpoſe better, this has been uſed to this day.

Mr. *Belidor* has propoſed a new method of moving draw-bridges, in his *Science des Ingenieurs*, that ſeems to be preferable to any other hitherto known: which is, inſtead of a baſcul, he fixes two cylindrical weights to the chains, which move in a curve on each ſide of the paſſage, in ſuch a manner, that the motion of the bridge is always uniform, provided, theſe weights are properly adapted; ſo that without ſpoiling the front of the building, or ſhaking it, two men may move it up and down with the greateſt eaſe.

Thoſe young engineers, who are deſirous of knowing how this curve is conſtructed, and the weights are applied, may conſult that author.

Of fixed or immoveable BRIDGES.

Fixed or common bridges are either built with wood or ſtone, and ſometimes with both; they are of various lengths, according as the ditch or river is leſs or more broad; they differ likewiſe in their breadth; for thoſe built over the ditches of a fortreſs, are ſeldom above 14 feet broad, which is ſufficient for two carriages to paſs in breaſt, though they never allow above one at a time: but bridges built over large rivers, are from 20 to 36 feet broad: That at *Fulham* is 22 feet broad, and *Weſtminſter* bridge 44, including the foot paſſages, and parapet walls.

When the bridge is to be built with ſtone, and the ditch is dry; the manner of laying the foundations of the piers, is the ſame as that of walls; it muſt only be obſerved, that as the piers ſupport a great weight, the baſe of the foundation muſt be made large in proportion; and they are always piled, and have a wooden grate over them, unleſs the bottom be rocky, or otherwiſe very hard: But when the ditch is wet, two rows of dove-tail piles, or planks, are drove round the foundation, at about 6 feet diſtance from it, and 4, 5, or 6 feet from each other; and the interval between theſe two rows of piles, is rammed full of clay, ſo as to keep the water out; or elſe, two rows of common piles are drove as before, of 3, 4, or 5, diſtant from each other, and to theſe piles are nailed boards at the inſide, and then the interval is filled with rammed clay as before.

This being done, the water is pumped out, and the foundation ſunk, as before: This method will ſerve in moſt caſes, excepting in deep water, where the current is very great: As to the proportions of the piers, in regard to the width of the arches, and the length of the arch-ſtones, they will be given in the latter end of this work.

If the bridge is made of wood, after the ditch has been ſunk to its proper depth, rows of piles are drove a-croſs the length of the bridge, at 10 or 12 feet diſtant from one another; the length of theſe rows is equal to the breadth of the bridge; and 4, 5, or 6, piles in each of them; when they are drove in as far as they will go; the upper part is made level, and bearing beams laid over them, into which they are tenanted; over theſe the tie-beams are laid, and then the planks. The firſt figure repreſents the elevation of ſuch a bridge, the ſecond the plan, and the third the ſection.

Plate XV.

The piles A, are a foot ſquare, and the bearing beams B, 14 inches broad, and 15 or 16 high, and the tie-beams C, 8 inches broad, and 12 high; as to the binding joiſts D, they are about 8 inches high, 6 broad; the planks are 4 inches thick; the poſts E about 4 by 6 inches, the top-rails *d*, about the ſame dimenſions; the middle rails *e*, and ſtruts *f*, are ſomewhat leſs than the former.

The bearing-beams B, are ten feet from each other, and ſupported by five piles each, and often with more, that is, when the bridge is very high: Theſe piles ſhould open below, as is repreſented in the ſection, figure 3; but as it is eaſier to drive them vertically, they are generally in that poſition; but ſince Mr. *Vaulvois's* new invented machine, they are as eaſily drove obliqely as upright; we chooſe this poſition, as making the bridge ſtronger and firm: If the foundation is hard and ſtony, the piles are ſhod with iron: The abuttments of all bridges are always made of ſtone, becauſe the firmneſs and ſtrength of the bridge depends very much thereon.

When a bridge is made over a navigable river, the middle opening between the piles is made wider than the reſt, in order that boats and ſmall craft may paſs through; and to prevent them from running foul on the piles, two or three planks are nailed on them, a little above the ſurface of the water. When the current is pretty rapid, it is neceſſary to add breakers; that is, two rows of piles are drove within five or ſix feet of each other, and two piles in the center line between them, at about ſix or eight feet diſtance from the bridge, ſo as to preſent a point on each ſide; theſe piles are braced to the others with timbers of about 4 by 5 inches, in two or three places; there are alſo boards nailed to them, in the ſame manner as we have mentioned before. This is the way that *Fulham* bridge was built; but thoſe over the ditches of a fortreſs require no ſuch precautions.

As the piles of wooden bridges are liable to rot very ſoon, in ditches which are ſometimes wet, and at others dry; the beſt way to make the work durable, is to lay a foundation of maſonry under them, as high as the higheſt water, upon which ſtrong beams are laid, into which the piles are fixed with tenants; this will make the bridge laſt much longer, and thereby, the often repairing is avoided, which is not only expenſive, but likewiſe very inconvenient in the ſtopping the paſſage out and in of the place.

To prevent the carriages from deſtroying the planks, ſand and gravel is laid over them, of about a foot or more deep; and very often they are paved, eſpecially, thoſe of fortified places; the gravel or pavement is made higher in the middle than at the ends, that the rain water may run off freely, and not rot the wood: This may be ſeen in the third figure, as likewiſe in the ſecond; where one part repreſents the gravel or pavement, and the others, the planks and the binding joiſts.

Some engineers drive the thickeſt part of the piles foremoſt, and on the contrary, others the ſmalleſt; the reaſon the former give for their practice, is, they ſay, that timber ſhould be uſed in the poſition they grow, whereby they will laſt longer; becauſe the fibres or grain of the wood being as it were adapted by nature to that poſition; whereas the latter affirm, on the contrary, and I think, with good reaſon, that being placed ſo, the wet will enter more eaſily in thoſe parts, where the branches have been cut off, and of conſequence, the wood will ſooner decay: but if they are in a contrary poſition, the water will run off, without being able to enter through the pores of the wood.

As our deſign is not to give a compleat treatiſe on bridges, but only ſo much as is neceſſary for a young engineer to know, and what moſt commonly happens in practice; we ſhall enter no farther into the manner of making all ſorts of wooden bridges, either with a ſingle arch, or with a great many; neither ſhall we ſay any thing of turning or flying bridges, as being uncommon in this country; we ſhall add only ſomething relating to bridges of communication from one work to another; as relating more immediately to an engineers buſineſs.

As the beſiegers endeavour always to deſtroy theſe bridges if poſſible, either with fire, ſhells, or ſhot; in order to hinder the troops in the outworks from being relieved or ſuccoured by the garriſon, and to obſtruct their retiring, when hard preſſed: To prevent this, theſe bridges are made as low as is poſſible, that is, they are made even with the ſurface of the water, and ſometimes a foot under it; and to ſave expences, piles are drove in the manner mentioned above, oppoſite to each other, and covered with a tie-beam; this is repeated at every ten or twelve feet diſtance, quite croſs the ditch, like ſo many truſſes; over which planks are laid, when there is occaſion to paſs over, and not before; at all other times theſe planks are kept in ſtore-houſes.

When there is a ſufficient depth of water, a good number of boats are alſo kept to paſs from the curtain to the ravelin, in caſe the bridges ſhould fail: thoſe that go from the ravelins to a counterguard, lunet, tenaillon, or into the covert-way, are always placed near the extremity of the faces, where a part of the parapet is cut off, to paſs by, or elſe a paſſage is made through it for that purpoſe.

SECT. XVI.

Of BARRIERS, GATES, *and* PORTCULISSES.

Plate XV. THE fifth figure in this plate repreſents a barrier-gate, ſuch as are made in the covert-way, at the entrance of a town, or in the paſſages cut in the places of arms, through the glacis; which is about 14 or 15 feet wide, and 10 feet high: the two ſide-poſts are from 10 to 12 inches ſquare, the part which is ſunk into the ground is left rough, and

about ſix feet long; the threſhold is as broad as the poſts are thick, and about ſix inches high: the frames of the gates are from 5 to 6 inches ſquare, and the planks 3 inches thick. Theſe gates are locked by an iron bar, turning about a bolt, ſo as that when one end raiſes, the other turns down, and one end is catched by an iron hook, whilſt the other is faſtened with a padlock.

The fourth figure repreſents a gate made under the covered gate-way; each ſide turns upon a ſtrong iron pivot, ſtanding on an iron ſocket, and are faſtened above to the wall, with hooks and hinges, much in the uſual manner of common doors; the outſide is covered with iron bars, in the manner repreſented here, for about eight feet high, and the parts between the bars, are drove full of diamond headed nails, to prevent their being cut open: In one of theſe gates, is made a wicket, in order to paſs through, when there is any danger of ſurprize, and in the morning before the party of men, that is ſent out to reconnoitre and ſee whether any enemy appears, is returned; the upper part of the gate is left plain, without any iron, becauſe there is no danger of cutting it there.

The fifth figure of this plate repreſents a harrow or port-culiſs, which is drawn up by means of two chains fixed to the upper ends A and B, and the other ends are faſtened to a wooden roller, with a handle on each ſide, which, when turned round, the chains roll upon it, and lift up the gate, and faſtened above, by two ſtrong bolts: the lower croſs bar is covered with an iron flat bar from one end to the other, as likewiſe the rails or uprights as high as a man can reach, to prevent its being cut open.

Theſe portculiſſes are, in my opinion, better than thoſe called organs, becauſe if an enemy ſhould come ſo near as to cut it open, it will not be ſo eaſily done, if they are well covered with iron; and the men behind them may fire through it with very little danger;

whereas, the enemy muſt be very much expoſed to their fire: beſides, there might be an opening left above, to throw ſtones and blocks of wood upon thoſe that dare approach them.

SECT. XVII.

Of SENTRY-BOXES and NECESSARY-HOUSES.

FORMERLY ſentry-boxes were made of hewn ſtones, and placed on the ſailant angles of the baſtions, ravelins, and other outworks, and fixed to the walls; as they may be ſeen in moſt fortified towns in *France*, with a flower de luce at the top of them: but it has been found by experience that they ſerve as marks for the beſiegers to direct their approaches by, for which reaſon, they build no more in this manner: the preſent method is to make them of wood, and ſo as to be moved from one place to another; and they are moſtly placed at preſent upon the middle of the parapets of the faces; and wooden ſteps are made to get up, or ſlopes are ſometimes cut into the parapet for that purpoſe; by which the enemy has it not in his power, to make any advantage of their ſight; theſe wooden ones are, beſides, leſs expenſive, and anſwer the intent full as well, which ought always to be conſidered in every kind of work whatſoever.

Plate XV. The figure given to ſentry-boxes, is either pentagonal or ſquare; we made it a pentagon, as may be ſeen in the plan, figure 6, and the elevation, figure 7, as being more convenient; for by turning the point outwards, the adjacent parts are better diſcovered from the ſides next to that angle: the ſides are about four feet long, and ſix feet high; the timbers of the baſe ought to project about a foot each way, ſo as to have a good baſe to ſtand upon, to prevent

the wind from blowing it down; and if this baſe is not ſufficient, it may be pinned down by ſtakes: In each ſide is a hole to look out, of 4 inches broad, and 8 high: as the plan, and elevation of this ſentry-box is ſo plain, there requires no further explanation.

The ſentry-boxes placed near the governor's houſe, powder-magazine, ſtore-houſes, *&c.* are made of a ſquare form, becauſe the ſentry has but one or two places to obſerve: each ſide of the baſe is four feet, and the box ſix high, beſides the covert: and they are made ſo light as to be eaſily turned about, or carried from one place to another.

Public boghouſes fall likewiſe under the care of the engineer: they ought to be placed over rivers, or ſtanding water, if it can be done, to prevent, if poſſible, the ſtench from becoming nauſeous; but where this cannot be done, they are placed on the curtain, where a paſſage is cut through the parapet; and ſupported with braces againſt the wall, ſo as to hang over the ditch: but care muſt be taken, not to place them too near the ſally-ports, otherwiſe, they will make the paſſage diſagreeable. But, in my opinion, if they were placed at the ſlope of the rampart, over the common-ſhores, it would be much better, becauſe the rain and other waters of the ſtreets would carry off all the naſtineſs, which makes them ſo diſagreeable.

SECT. XVIII.

Diſtribution of HOUSES *and* STREETS.

TOWNS were formerly built any how, according to the builder's fancy, without the leaſt regard to regularity or beauty: but now-a-day, when a place is fortified, which is not occupied by any houſes or other buildings, great care is taken, to make every

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Plate XIV

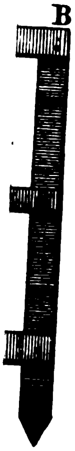
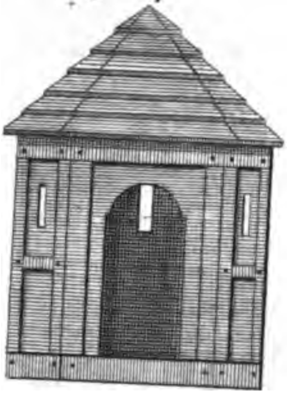
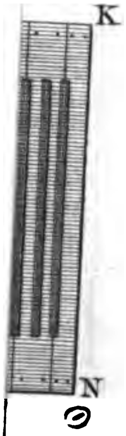


Fig. 7





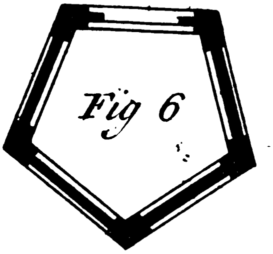


Fig 6

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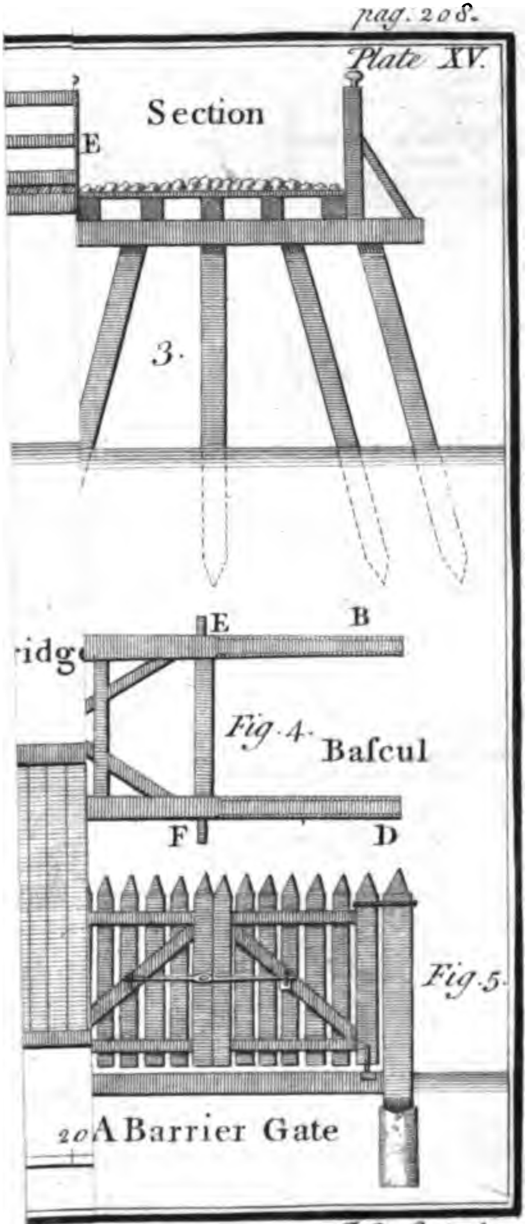

J Couſe ſculp

UNIV. OF MICH.

part within as regular as is poſſible; for which reaſon, care is taken to make the ground level, at equal diſtances from the center of the place, and deſcending gradually from that point in an eaſy ſlope towards the ramparts; that the waters in the ſtreet may run into the ditch.

Some *German* engineers, will have the ſtreets to part from the center of the place, and directed to the middle of the baſtions and curtains, pretending that thereby, the troops aſſembled upon the parade, may render themſelves in a ſhorter time to any part of the rampart, where their preſence is required; this might be well for the defence; but then all the houſes, and other buildings are made with a bevil, which is ſo great an inconveniency, that I believe, this method will never be put in practice.

It is not only the regularity of the ſtreets, which is ſufficient, but likewiſe the rightly placing all the military buildings, ſuch as the governor's houſe, guard-houſes, ſtore-houſes, and magazines of different kinds: The governor's houſe is aptly placed in the middle of the ſide of the great ſquare, oppoſite to the great church, ſo that he may ſee the troops, parade, and the garriſon under arms, from his windows, or gallery; there ſhould likewiſe be a guard-room in that ſquare, from which the ſentries placed at the governors door, and near the magazine are taken: the other guard-rooms are placed near the gates, and ſometimes one near the barracks: The ſtore-houſes and magazines are beſt near the ramparts, where they are at hand in caſe of a ſiege: As to the powder-magazines, they are always placed in the gorges of the baſtions. In places near the ſea, or navigable rivers, the naval ſtore-houſes muſt be as near the harbour, where the ſhips lie, as poſſible; on the contrary, thoſe for land ſervice on the oppoſite, or land ſide; as we have mentioned in the firſt book of fortification, where we have given the conſtruction of thoſe places.

When a town is very large, and therefore much room to build upon, it is neceſſary for the public uſe, to make ſeveral ſquares; but on the contrary, if the place is but little, and no room to ſpare, there muſt at leaſt be one, in the center of the place, whoſe bigneſs ought to be in proportion to the extent of the fortification, and conſequently, to the number of troops required to defend it: For this ſquare not only ſerves as a market place, but likewiſe, to draw up the troops and parade on it. Mr. *Belidor* thinks, that a fortreſs of ſix baſtions, whoſe exterior ſide is 180 fathoms, ſhould have a ſquare, whoſe ſide is from 40 to 45 fathoms, a place of ſeven baſtions, one whoſe ſide is from 55 to 60; that of 8 baſtions, from 70 to 75; that of nine or ten baſtions, from 80 to 85; and laſtly, that of eleven or twelve baſtions, from 90 to 95 fathoms; however, he ſays, that the engineer employed in theſe works, will be able to judge of the proper bigneſs which theſe ſquares ought to have.

There is commonly an open ſpace left at the entrance of every gate of the town, in order that the guard-houſe, which is made there, may have room before it, to draw up the guard, and, in caſe of danger, to defend the gate and adjacent places: beſides, theſe openings have a good appearance, and ſerve alſo for the carriages to get out of the way, when any others are coming in.

In regard to the ſtreets, the principal ones ſhould go from the great or principal ſquare in the center, directly to the town-gates; to the ramparts, and to the citadel or harbour, if there is any; in order to be enfiladed by the guns and troops, placed in that ſquare in caſe of any danger or ſurprize: It muſt be obſerved, that the croſs ſtreets are all parallel to one another, and perpendicular to the former; ſo that all the buildings be at right angles to each other.

The principal ſtreets are generally 36 feet wide, in order that three carriages may paſs a-breaſt at a time, or if two of them ſhould ſtop, another may paſs by, as likewiſe room for the foot paſſengers; but in regard to the other ſtreets, they need not be ſo large; if they are from 18 to 24 feet wide, it will be ſufficient, becauſe there paſs ſeldom above one or two carriages at a time.

The diſtance between one ſtreet to that which is parallel to it, is various; Mr. *Vauban* made them only the breadth of three houſes, at *New Briſac*; that is, but one between the two corner houſes; which, in my opinion, is not ſufficient, becauſe there is ſcarcely any room left behind to build warehouſes, or ſhops, for workmen, which are abſolutely neceſſary; neither is there any room for gardens or openings for the light and air to paſs freely, both uſeful for the preſervation of the inhabitants.

We ſuppoſe that each houſe takes up 36 feet in the front, and the interval between the parallel ſtreets is equal to the breadth of four houſes, or 144 feet; ſo that if the houſes are 36 feet deep, each of them will have an opening behind of the ſame extent, excepting the corner houſes; either for a garden, or to build ſhops or ſtore-houſes: we ſuppoſe that the ſhops to work in are all behind, and in the front only thoſe to expoſe and ſell the goods.

Plate XVI. We made but one ſquare in this deſign, whoſe ſides are 75 fathoms, but if it ſhould be thought neceſſary to make more, one of the ſpots occupied by houſes terminated by four ſtreets, in the moſt convenient place may be uſed for that purpoſe; and it is there where the market for dry goods may be kept, and a town houſe ſhould be built.

The governor's houſe is ſuppoſed to be in the great ſquare, marked by the letter B, and the great church oppoſite to it, marked C: the governor's houſe takes up as much room as three others, and his garden as much as two: ſo that the houſe is 108 feet in front, and 36 in depth, and the garden 36 feet broad, and

72 long: and if this is not thought ſufficient, the whole opening behind may be taken into his garden.

It is alſo common to build a fountain in the very center of the place, or great ſquare, decorated in a neat manner, with four ſpouts facing the four pincipal ſtreets: For ſince water is the moſt neceſſary thing wanting in a garriſon, both for men and cattle; there cannot be too much care taken to ſupply the place with it: for which reaſon, water is brought from ſprings, or rivers near hand, by means of pipes, and engines if neceſſary, at the ſame time that the town is built; there ought beſides this, in the center of the place, to be ſeveral others contrived in the corner of the ſtreets, if the place is large, to ſupply every part of the town plentifully.

When an old place is fortified where there are houſes, the ſtreets are left as they were; the principal ones are only widened and made ſtrait if poſſible, either by demoliſhing the old houſes, and building new ones, or elſe waiting till the old ones decay, and then obliging the inhabitants to build them in a ſtrait line: this is often practiſed by the *French*, when they fortify old towns, as I have ſeen at *Douay*, and other places: it is true, that this is againſt the laws of *England*; but any thing that tends to the benefit of the public in general, ought to be preferred before the obſtinacy of private people, who loſe nothing by it.

In new places built abroad, in plantations where there is ſufficient room, and where the fortification often conſiſts of the town-wall, and ditch only; I would make the intervals between the ſtreets greater than what we have repreſented here in this plan, as likewiſe all the bye ſtreets about 30 feet wide: For nothing contributes more to the wholeſomneſs of the place, as well as agreeableneſs, than fine large ſtreets, and great openings behind the houſes, planted with trees, eſpecially in warm climates; beſides, all the ſhops to work in, ſhould be built there, and no others ought to be permitted in the front of the ſtreets, than thoſe for the ſelling goods, as we have obſerved before.

The engineer employed in the building of *Halifax*, in *Nova Scotia*, has, in my opinion, committed a great miſtake, in building the ſtreets ſo near to each other as he did; for each houſe is 36 feet in front, and 72 in depth, and no opening is left behind, as I have been informed, by an officer that was there, and employed in the works. This miſtake can ariſe from no other reaſon, than the manner of building fortified places in *Europe*: but the caſe is quite different, becauſe places have a great number of outworks, beſides the body of the place; for which reaſon, we are obliged to crowd the buildings as much as we can, that there may be room for the inhabitants, beſides a large garriſon: whereas abroad, where the fortification is inconſiderable, the place ſhould be made as pleaſant, and convenient as poſſible.

It was ſaid, the few people that went there, were not ſufficient to clear a larger ſpot of ground; but in anſwer to this, I ſay, they need not clear more ground at firſt than to build upon; and leave the openings behind, for another opportunity, when they have more time; by doing this, the wood left may ſerve for timber to build out-houſes, and the branches for fewel to burn, when perhaps, they muſt go far for it, and are expoſed to the inſults of the *Indians* at the ſame time.

The ſtore-houſes for ammunition and artillery, being military edifices, and requiring much room, it is not eaſy to determine their ſituations, becauſe they depend on many circumſtances, which cannot ſo well be known as upon the ſpot; it is neceſſary to obſerve, that they ſhould be ſeparate from one another, as well as from other buildings, to prevent accidents as much as is poſſible, which may happen by ſetting the adjacent buildings on fire, either by chance, or by the contrivance of an enemy: When there is a brook or river that paſſes through the town, it is requiſite, for the good of the ſervice, that the ſtore-houſes ſhould be near it; to bring timber and other materials, as well as ſtores, by means of water carriages.

We placed the ſtore-houſes and magazines here, near the curtains, which have no town-gates; ſuch as are marked D; becauſe they are near at hand, to tranſport them upon the rampart, where they are wanted in caſe of a ſiege: and the triangular openings formed by the ſtreets, may ſerve them as yards, which ſhould be walled in; they are likewiſe near the barracks, which is another conveniency; for as ſoldiers are commonly employed in ranging and moving them, they are near at hand upon all occaſions.

The barracks are generally placed near the rampart of the curtains, as marked here by the letter G; with pavillions H at the ends, which are deſigned for the the officers lodgments; this is undoubtedly the propereſt place for them; becauſe an open ſpace may be left before them to draw up and exerciſe the troops; the detachments in time of war may be more privately made for any enterprize that might be thought neceſſary, which could not ſo well be done in any other place; and the troops are quite ſeparated from the inhabitants, with whom they do not always agree.

As the tap-houſes and bake-houſes, for ammunition-bread, are neceſſary for the ſubſiſtence of the garriſon, they ought to be built near the barracks, and ſo as to have a guard-room not far from them, in order to prevent any riotous proceedings, that might happen; and as to the hoſpital, it is almoſt needleſs to mention, that it ſhould be placed in ſome bye place or other, ſo as to be ſeparate from the inhabitants, and noiſe of the workmen; eſpecially near a brook or river, in caſe there is any that paſſes through the town.

This is nearly all that can be ſaid in regard to this ſubject, when the place is large; but in ſmall forts there requires not ſo many ſtore-houſes, which however are always placed near the rampart, In ſuch places,

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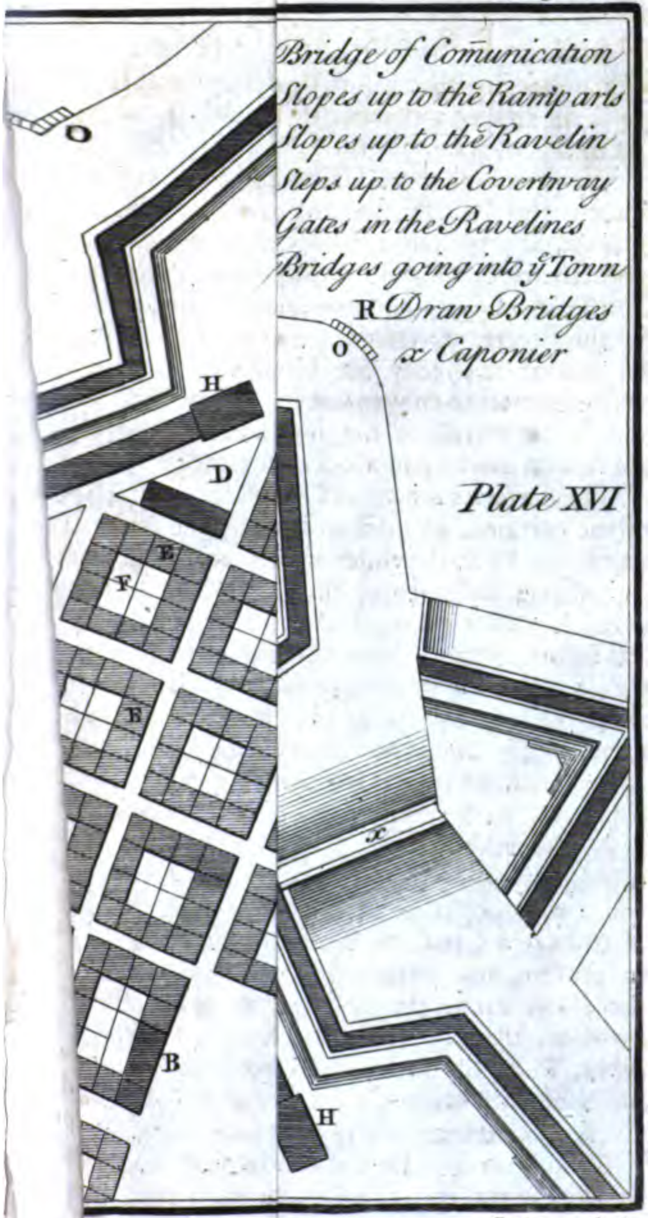

Plate XVI

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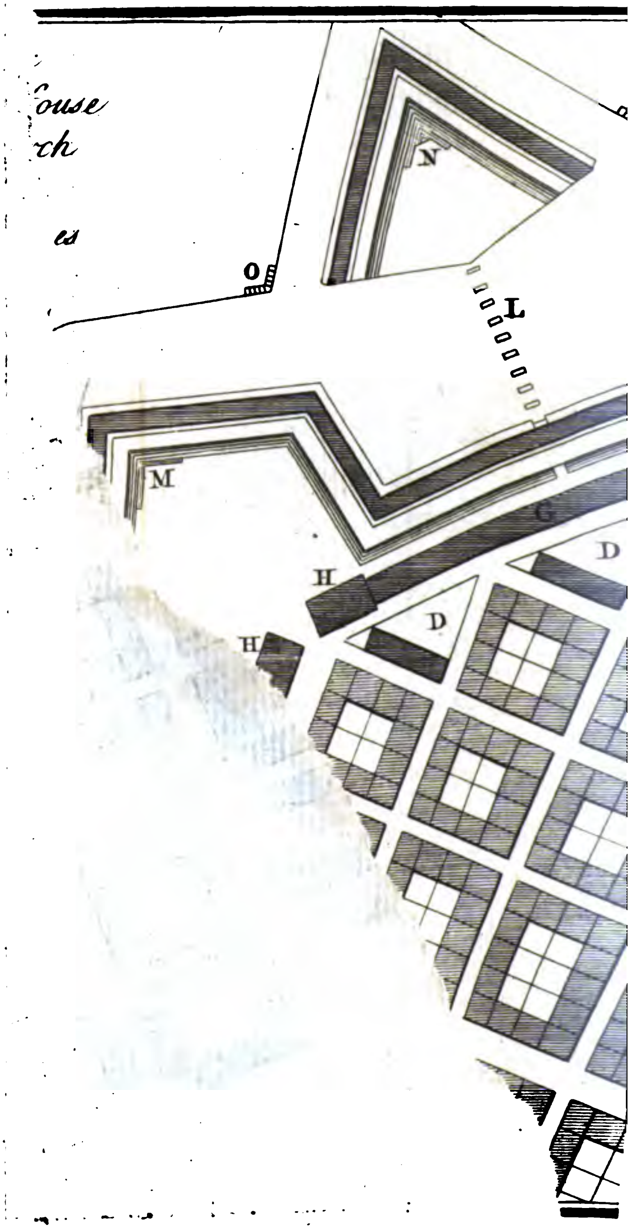
UNIV.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where there are harbours or citadels, regard muſt be had to them in the placing theſe buildings; but the ſubject being ſo plain and eaſy, it requires no farther explanation; ſince a little practice and common ſenſe, will ſuggeſt the neceſſity of placing theſe buildings in the moſt convenient manner: but the execution of theſe, and all other military buildings, requires much more capacity and knowledge; in order to make them ſolid, and at the ſame time convenient; which we ſhall diſcuſs more particularly, by treating of them each ſeparately.

We have omitted ſeveral other things too trifling to be mentioned, which the reader will partly ſee in the ſixteenth plate, which beſides will ſerve as a further illuſtration to what has been mentioned; and what remains to be done, we muſt leave the ſagacious reader to find out himſelf, the ſubject being too copious to treat particularly of all the minute parts.

SECT. XIX.

Of POWDER-MAGAZINES.

FORMERLY powder-magazines were made in a quite different manner from thoſe at preſent; they placed the powder in towers that had been built in the town-walls, by which they became liable to many accidents; for when the powder happened to be ſet on fire, either by chance or by ſome concerted ſcheme of the enemy with the inhabitants, it opened the town, and made a breach for the enemy to enter, as it happened at *Aire*, according to Mr. *Belidor*, when that place belonged to the *Spaniards*: The *French*, who then beſieged it, having got intelligence from ſome inhabitant, found means to ſet the powder on fire, that was placed in one of the baſtions; which had ſo great an effect, as to make a large breach, and as ſoon as the beſiegers had prepared for an aſſault, the garriſon ſurrendered, whereas, without this accident, they might have defended themſelves much longer.

Finding by experience, that the building magazines in the rampart, was of dangerous conſequence; they are now placed in different parts of the town, and made of various figures; but it was a great while before the right one was found: the moſt common, had ſeveral pillars in the middle to ſupport the arches; but to bring theſe double arches under the ſame roof, the top muſt be loaded with ſo great a quantity of maſonry as almoſt burſt the arches: finding this method inconvenient, it was agreed to make them of one ſingle arch, as being much better than the former: the form of this arch was of the *Gothic* kind, and in order to get more room for lodging the powder, a floor was made at the ſpring of it.

Plate XVII. But Mr. *Vauban* having obſerved in ſeveral ſieges, that theſe kind of arches were too weak, and that the floor loaded the piers very much to no purpoſe; ſince prudence requires not to lodge ſo much powder in the ſame place; and being better to divide it into ſeveral parts, he abſolutely rejected all the different methods till then followed, and propoſed a new one, much more perfect; and which is that repreſented by the firſt and ſecond figures, and is the only one hitherto executed with ſucceſs; though ſomething may be changed for the better, as we ſhall ſhew hereafter.

If we may believe what has been ſaid on that ſubject, we are told, that there was thrown upwards of 80 ſhells upon a magazine of this ſort, at *Landaw*, without doing the leaſt damage to the vault: the ſame thing is reported to have happened at *Ath*, and in ſeveral other places. Mr. *Demus* director of fortification, and a perſon of good reputation, aſſures, that in the ſiege of *Tournay*, by the duke of *Malborough*, where he ſerved, there was thrown upwards of 45000 ſhells into the citadel, and the greateſt part of them fell upon two powder-magazines of this ſort, and yet neither of them was damaged; whereas there were ſome built with *Gothic* arches, that were deſtroyed by three or four ſhells that fell upon them, notwithſtanding that they had been covered with five or ſix feet of earth, ſometime before the ſiege begun.

The dimenſions of Mr. *Vauban's* magazines, are as follow; the plan is 60 feet long, clear within, and 25 broad; the foundations are 9 or 10 feet thick under the long ſides which ſupport the arch; and theſe ſides he made 8 or 9 feet thick, according as the maſonry was good or indifferent, and 8 feet high from the foundation to the ſpring of the arch; ſo that making the floor about two feet from the ground to keep it free from all dampneſs, there remained 6 feet for the height of the ſtory.

The thinneſt part or hanches of the arch is three feet thick, and the arch made of four leſſer ones, one over the other, and the outſide of the whole terminated in a ſlope to form the roof; from the higheſt part of the arch to the ridges is 8 feet, which makes the angle ſomewhat greater than 90 degrees; the two wings, or gable ends, are four feet thick, raiſed ſomewhat higher than the roof, as is cuſtomary in other buildings; as to their foundations they are 5 feet thick, and as deep as the nature of the ground required.

The piers or long ſides are ſupported by four counterforts, each of ſix feet broad, and 4 feet long, and their interval 12 feet; between the intervals of the counterforts, are air holes, in order to keep the magazine dry and free from dampneſs; the dices of theſe air-holes are commonly a foot and a half every way, and the vacant ſpace round them three inches, made ſo as the in and outſides be in the ſame direction, as may be ſeen by the plan; the dices ſerve to prevent an enemy from throwing fire in, to burn the magazine, and for a further precaution, it is neceſſary to ſtop theſe air-holes with ſeveral iron plates, that have ſmall holes in them like a ſkimmer, otherwiſe fire might be tied to the tail of a ſmall animal, and ſo drive it in that way; this would be no hard matter to do, ſince where this precaution has been neglected, egg-ſhells have been found within, that have been carried there by weaſles.

To keep the floor from dampneſs, beams are laid long-ways, and to prevent theſe beams from being ſoon rotten, large ſtones are are laid under them, theſe beams are 8 or 9 inches ſquare, or rather 10 high and 8 broad, which is better, and 18 inches diſtant from each other; their interval is filled with dry ſea coals, or chips of dry ſtones, then over theſe beams are others laid croſs-ways, of 4 inches broad, and 5 high, which are covered with two inch planks.

To give light to the magazine, a window is made in each wing, which are ſhut up by two ſhutters of 2 or 3 inches thick, one within and the other without; that which is on the outſide is covered with an iron plate, and is faſtened with bolts, as well as that on the inſide. Theſe windows are made very high, for fear of accidents, and are opened by means of a ladder, to give air to the magazine in fine dry weather.

There is likewiſe a double door made of ſtrong planks, the one opens on the outſide, and the other within; the outſide one is alſo covered with an iron plate, and both are locked by a ſtrong double lock; the ſtore-keeper has the key of the outſide, and the governor that of the inſide: the door ought to face the ſouth nearly if poſſible; in order to render the magazine as light as can be, and that the wind blowing in may be dry and warm. Sometimes a wall of 10 feet high is built round the magazine about 12 diſtant from it, to prevent any thing from approaching it without being ſeen.

Here we take not ſo much precautions, for I never did ſee any with double doors, or ſhutters, and they are built in ſo ſlight a manner, that it would be an eaſy matter to deſtroy them. I have ſeen a project for mending a powder-magazine at *Minorca*; there were to be no leſs than four doors, and as many windows as are commonly made in a dwelling houſe: there was to be likewiſe a brick floor, and to render the work compleat, croſs-walls were to be built within, at every twelve feet diſtant: and yet this project was contrived by a perſon of the greateſt repute for his ſkill in engineering; and would, in all probability, have been executed, had I not prevailed with the ſurveyor general at that time to lay it aſide.

Such a magazine as this will hold about 200,000 pounds of powder, when the barrels are ſix above one another, which however is not done, but in caſe of neceſſity, becauſe when they lie ſo much on each other, it is very troubleſome to remove them, and change their poſition, which ought to be done once a year at leaſt; otherwiſe the ſalt petre, being the heavieſt ingredient, will deſcend into the lower part of the barrel, and the powder above will loſe much of its goodneſs; but to prevent the barrels from rolling, when ſome are taken off, two wooden poſts are erected, of about 4 or 5 inches ſquare, between every 10 or 12 barrels, by this means they may be piled up as high as you pleaſe, or taken off without any danger.

Mr. *Belidor* would have brick walls made under the floor, inſtead of beams, and a double floor laid on the croſs-beams; which does not appear to me to be ſo well as the manner propoſed here; the reader is, however, at liberty to chooſe that method he likes beſt.

Inſtead of making the ſide walls 8 feet thick, as Mr. *Vauban* does, we have made ours here but ſeven, and turned the counterforts contrary to his poſition; that is, inſtead of being 6 feet broad, and 4 long, ours are 6 feet long, and 4 broad, which ſtrengthen the walls very much; as his were only 12 feet diſtant from each other, ours become 14 feet aſunder, ſuppoſing the extreme ones to be within a foot from the inſide of the wings produced.

It is likewiſe to be obſerved, that inſtead of making four arches one over another, each of them the length of a brick thick, in the manner of Mr. *Vauban*, we make but one continued arch three feet thick, which makes it much ſtronger, as it eaſily might be proved by what has been demonſtrated in the ſecond ſection. The reaſon of making our ſide walls ſeven feet thick only, inſtead of eight, according to Mr. *Vauban*, is, becauſe we found by the rules of mechanics, and the ſtricteſt computation, but 7 feet and two inches, when they are four feet long, and ſix broad, but by making them ſix feet long, and four broad, the walls are capable of a greater reſiſtance than his, and they being found ſtrong enough by a long courſe of experience, there cannot be the leaſt doubt, but that ours will be ſufficiently ſtrong.

In the theory of arches we made no allowance for friction, but conſidered the ſtones only according to their weight, whereas, in that of the walls which ſupport earth, we made an allowance of one third of the weight, for the friction, and yet our walls are as ſtrong as thoſe built by Mr. *Vauban*; it may ſeem contradictory to make no allowance here; but if it be conſidered, that the ſtones never cloſe and bed ſo together, as to make one continued ſolid, as the theory ſuppoſes; but on the contrary, lay often hollow, and the void ſpaces are filled up with bad mortar, it is a great while before theſe piers or walls are dry, and become capable of as much reſiſtance as is required: beſides, an allowance muſt be made to reſiſt the force of the ſhells thrown upon them, as has been obſerved in the ſecond ſection.

In order to ſucceed in theſe kind of buildings, it is highly requiſite that the engineer ſhould watch the workmen continually, in order to make the walls as ſolid and compact as poſſible, that the ſtones or bricks bed well, and no holes big enough to hold a ſtone or brick to be filled with mortar: And laſtly, to make uſe of the beſt materials to be had thereabouts; and when the arch is built, the centers ſhould be left to ſupport them, at leaſt for ſix months, that is, till the work is ſettled and dry, otherwiſe the arch is in danger of tumbling down, or elſe the walls muſt be made ſtronger than they need to be.

The third and fourth figures, repreſent the plan and ſection of a large magazine, for ſtowing a great quantity in the ſame place: the piers or ſide-walls, which ſupport the arch, are here 10 feet thick, 72 feet long, and 25 high, from the foundation to the ſpring of the arch; the middle wall which ſupports the two ſmall arches of the ground floor, is 8 feet high, and 18 inches thick, as are likewiſe the arches; the thickneſs of the great arch is 3 feet 6 inches, and the counterforts, as well as the air-holes, are the ſame as in the former.

Such large magazines as this, are by no means to be built in fortified towns, becauſe if any accident ſhould happen, all the powder would be loſt at once, whereby the place would be obliged to capitulate; but in ſome inland part of the country near the capital, where no enemy is expected, they might be uſed, as for a general magazine, and that from thence the powder might be diſtributed to the ſeveral places where it may be wanted: yet, in my opinion, it would be better to make two ſmall ones, and place them at a proper diſtance, that if one ſhould be blown up by accident, the other might be ſafe.

The ridge of the roof makes a right angle in both theſe magazines, and it is neceſſary to obſerve, that as the foundations grow deeper, ſo they ought to increaſe in width; this is obvious from the common practice of making walls thicker as they increaſe in height; but no certain rule has hitherto been given, to know how much that increaſe is to be; ſuppoſing the foundation to project inwards, by ſix inches only, which ſeems to be ſufficient, ſince the walls never fall that way: then I would allow ſix inches for every foot and a half depth, on the outſide, ſo that if the foundation be ſix feet deep, its breadth muſt be increaſed by two feet divided into four ſteps; by this means you may know at all times how broad a foundation muſt be, when its depth is known. Although this rule is not founded upon a demonſtration, yet by the obſervations of common practice, it appears to be ſufficiently accurate upon all occaſions.

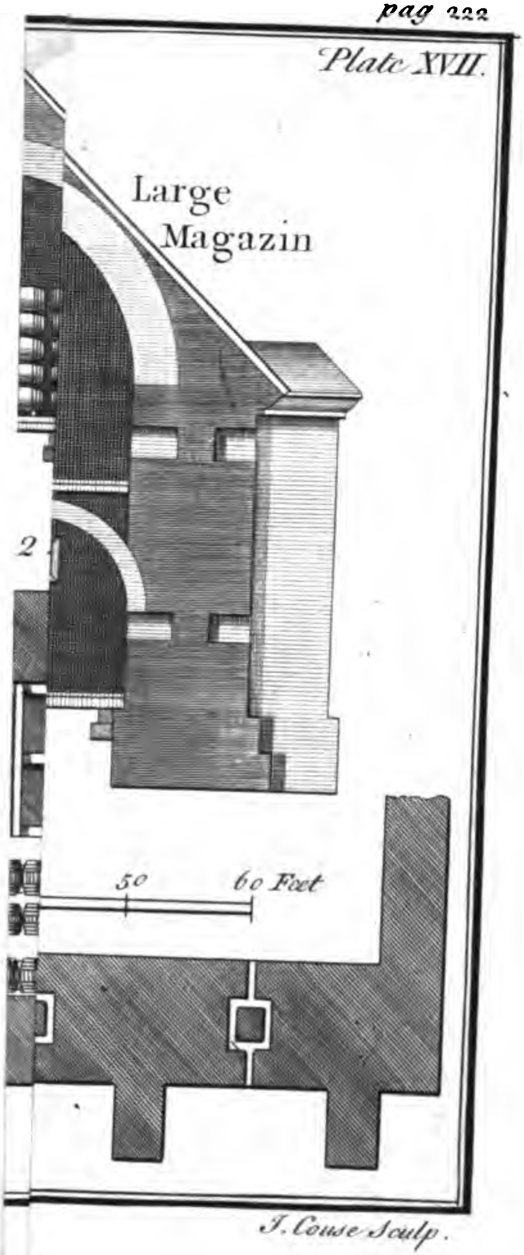
SECT. XX.

Of BARRACKS, HOSPITALS, *and* STORE-HOUSES.

Plate XVIII. BARRACKS are built now-a-day in all fortified places, to keep up the diſcipline, and good order in the garriſon: they have been found ſo uſeful, that no place is built without them; and experience ſhews, that thoſe garriſons which have them, are much more quiet, on account of the conveniency which non-commiſſioned officers have to viſit the quarters every evening, and to ſee the ſoldiers ſhut up in their quarters, which cannot be done when they are lodged amongſt the inhabitants, where they have the liberty of going out and in whenever they pleaſe; beſides, when the governor has a mind to make a detachment, or ſend out a party, he cannot do it, without the knowledge of the whole town: If any alarm happens, the garriſon cannot be aſſembled without great trouble and loſs of time; whereas, when there are barracks, every thing neceſſary for the good of the ſervice may be done with eaſe.

Barracks are built different ways, according to their different ſituations. When there is ſufficient room to make a large ſquare, ſurrounded with buildings, they are

Plate XVII.



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are very convenient, becauſe the ſoldiers are eaſily confined to their quarters, and the rooms being contiguous, any order may be executed with privacy, and expedition, and the ſoldiers have not the leaſt connection with the inhabitants of the place, which prevents quarrels and riots.

This diſpoſition of the barracks, is eſpecially convenient for the horſe and dragoons, becauſe they want a convenient place for the daily mounting their horſes; and in this caſe, the lodging-rooms are built over the ſtables, with a gallery ſerving for a communication from one room to another, quite round the building, with ſtair-caſes in the corners, and ſometimes another in the middle of each front; but care muſt be taken, to make the firſt row of lodging rooms pretty high, or elſe they will be darkened by the gallery above them.

When the barracks are built near the ramparts of the curtains, as Mr. *Vauban* has done in almoſt every place he fortified, they are compoſed of a large pile of building in a ſtrait line, for lodging the ſoldiers, with pavillions at the extremities for the officers: theſe barracks are generally two or three ſtories high, beſides the ground floor.

Between every two rooms in the front, is an entry of 8 feet wide, with doors to the four contiguous rooms, and a ſtair-caſe leading to the upper ſtories; as to the bigneſs of the rooms, Mr. *Vauban* made them 22 feet long, and 18 broad, in order to hold four beds each; I have ſeen ſome large enough to hold ſix beds, and with two chimneys in them; there were three men to each bed, which is the cuſtom in all the *French* garriſons, becauſe it is ſuppoſed, that one of the three is always upon duty, ſo that there is never but two in one bed at a time.

Our barracks here, at *Woolwich*, are but 16 feet each way, with three beds in each room, to hold ſix ſoldiers only, which is not ſufficient, becauſe it requires too large a building to quarter a whole regiment in them. The plan and elevation in the eighth Tenth plate, is much in the ſame manner, only we ſuppoſe four beds in a room, which they may hold; the rooms are 16 feet each way, though I think that if they were 20 feet long, and 18 broad, it would be much better; the ground ſtory is 11 feet high, the next to it 10, and the laſt but 8.

The outſide wall is two feet thick, and the partition, or croſs wall a brick and a half; for if theſe latter are thinner, every thing that is done, and ſaid, will be heard by thoſe in the adjoining rooms: the outward doors are 3 feet and a half wide, and 7 high, the inner ones 3 feet wide, and 6 and a half high; the windows are 3 feet wide, and 6 high in the ground floor, the upper ones have the ſame breadth, but their height diminiſhes in proportion to the height of the ſtory; that is, the ſecond row is 5 feet high, and the laſt but 4: the chimneys are 4 feet wide, and 18 inches deep, going partly into the wall, and project partly in the rooms.

The corner houſes, being deſigned for officers lodgings, have each an entry of 6 feet wide, with a ſtair-caſe and a cloſet of 5 by 6 feet at the further end: under the ſtair-caſe is another going down into the kitchen and cellars, which we ſuppoſe are built under the officers houſes; but in regard to the ſoldiers barracks, there is no occaſion to make either kitchen or cellars, as they have done at *Woolwich*.

The third figure in this plate repreſents the ſection of the elevation, where it may be ſeen that the ſtair-caſe goes ſtrait up from one floor to the other; but if this is found inconvenient, it may turn at half-way, with a landing-place: the roof is divided into two ridges, becauſe, it is both cuſtomary, and more convenient, than if it was continued, which would make it too high, and requiring longer timbers, makes it more expenſive.

Sometimes there are piazzas built before the barracks, as thoſe at *Dublin*, if I am rightly informed; which are very convenient; for when the troops are drawn up, and a ſhower of rain comes, they may ſhelter themſelves under it, to keep their arms dry, and when the companies are to be examined, in regard to their cloathes or arms, it may be done there at any time or ſeaſon.

In all garriſons it is neceſſary to build hoſpitals for the ſick and wounded; its bigneſs ought to be regulated according to the number of troops required to defend it in time of a ſiege, and it has been found by experience, that out of 25 men, there is generally one ſick; yet it ought to be obſerved, that in fortreſſes built in low or marſhy ground, there are more people ſick, than in places ſtanding on a high ground in good air.

Knowing nearly the number of ſick people, the number of beds wanted will alſo be known, and conſequently, the bigneſs of the building, which conſiſts of a long room to hold four rows of beds, and another above it; theſe rooms the *French* make 42 feet wide, and therefore if but two rows of beds be required, 20 or 21 feet will do; each bed ought to be 4 feet wide, and 6.5 feet long, and the diſtance from one bed to the next can be no leſs than 4 feet, ſo that as many times 8 feet as there are beds, will be the length of the room which is to hold but two rows of beds, or half that length, if it is to hold four rows.

Beſides theſe rooms, there muſt likewiſe be lodging rooms for a doctor, ſurgeon, their mates and attendants, for the nurſes and ſervants; a kitchen and laundry, as well as a yard to dry their linen: In ſhort, the building is to contain every thing neceſſary, both for lodging and conveniency of the hoſpital.

In regard to their ſituation, we have ſpoke of it already, but I muſt add, that if it is not poſſible to place it near a river, a canal might be cut to it, becauſe water is abſolutely neceſſary, for cleaning the apparel of the ſick and wounded; for neatneſs in general, is abſolutely neceſſary in ſuch places, where the ſmell of ſo many ſores, wounds, and other ſickneſs muſt otherwiſe be very offenſive.

We have not given any plans of hoſpitals, becauſe they may be conſtructed various ways, according to their ſituations and bigneſs, which an engineer upon the ſpot, will be acquainted with, and from thence regulate his draughts accordingly, and it would not be amiſs to conſult the doctor and ſurgeon about the ſeveral conveniencies to be made; this, and his own knowledge in building, will be ſufficient to perform ſuch a work in the beſt manner.

I had forgot that there is often a chapel built at one end of the great room, to perform divine ſervice, and when there are two rooms above one another, the upper one has a gallery looking into it, for the ſick to ſit in without being obliged to come down ſtairs.

The laſt publick buildings we have to treat of, are the ſtore-houſes for all kinds of ammunitions, great and ſmall guns, and, if the place is ſituated near the ſea or a navigable river, for cables, anchors, timber, and other neceſſaries, to repair and furniſh ſhips.

In a ſmall fortreſs, ſuch as a citadel or fort, a ſtore-houſe of a moderate ſize will be ſufficient to hold the ammunition, and other neceſſaries for the defence of the place, whereas in a large town lying near the border of a ſtate, it is neceſſary to have a ſpacious one for the artillery, in ſuch a manner as to contain every thing wanted in a field train.

A ſtore-houſe of this ſort, ought to be built near a river that may carry ſmall craft at leaſt, if poſſible; in this caſe a baſon ought to be made, to load or unload ſeveral boats at a time; ſuch a ſituation is of great importance, in regard to the ſaving expences; for it requires a great deal to tranſport a train of artillery with all

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Plate XVIII.

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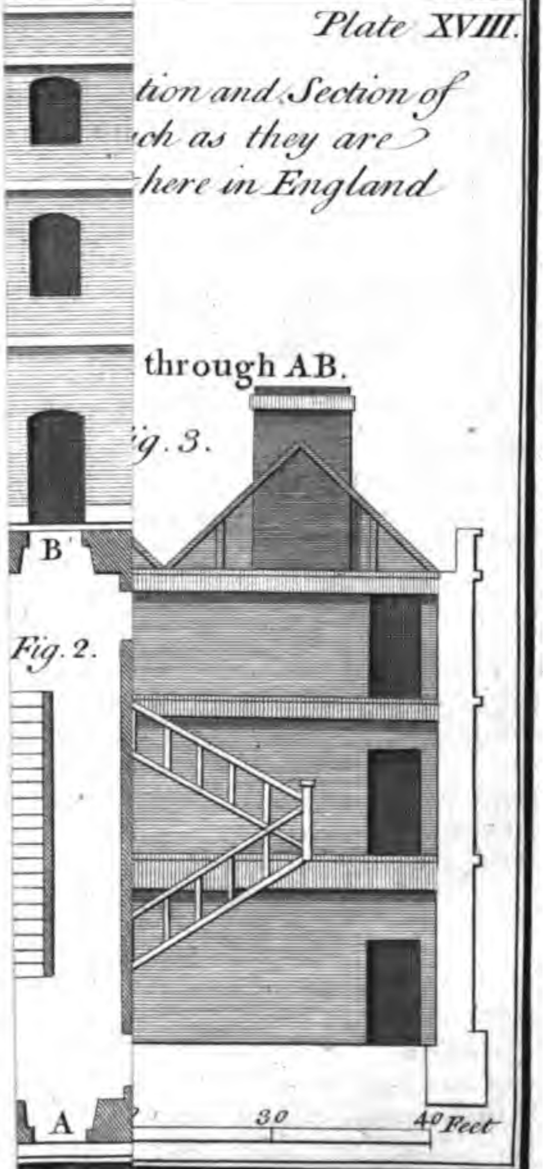
here in England



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all its appurtenances by land to any conſiderable diſtance. And as there is ſeldom any fortreſs built but near a great river or the ſea, it will always be in the power of the engineer to find a proper place for building the ſtore-houſe; and what nature wants may be ſupplied by art.

The ground floor of a ſtore-houſe ought to conſiſt in a ſhed to place guns and their carriages, tumbrels, ammunition, waggons, mortars, and their beds; in ſhort, all the other neceſſaries which are too heavy to be carried and depoſited above: there muſt likewiſe be forges for ſmiths, places for carpenters to work in, to hold iron and wood, and wheelwrights ſhops, and every thing of this ſort.

The firſt floor ought to contain an armoury, places to hold all kinds of ſmall irons, others for cordage, pontoons, and every thing neceſſary, that is light and eaſily tranſported. An engineer, who is not perfectly acquainted with every part belonging to the artillery, will not be able to form a right notion of a ſtore-houſe: there is ſuch a connection between the buſineſs of an engineer and that of an artillery officer, that neither the one nor the other can be maſter of his buſineſs, without being tolerably well acquainted with that of the other: I am ſenſible, that this will be ridiculed by many practitioners, but I leave the unbiaſſed intelligent reader to judge, whether this notion is right or not: As my intent, in writing this work is to inſtruct young engineers, it is no matter what thoſe ſay, who think experience is ſufficient to ſhelter their ignorance.

Plate XIX. To give an idea of theſe kind of works, we have repreſented the plan of the fourth part of a rectangular ſhed, in this plate, with the elevation of one of the inſides, executed at *Woolwich*; the width within is 33 feet, the length 282 one way, and 156 the other; the wall is 18 inches thick; having pilaſters 15 feet diſtance from each other, they are two feet broad, and project the wall by 9 inches; the elevation

is 16 feet high at a medium, for the building ſtands on a ſmall deſcent: the gate-ways, which are three in each front, and one in the other ſides, are 10 feet wide; the arches of the inſide walls are 8, as well as the height of the piers from the bottom to the ſpring.

Plate XX. Here are repreſented the elevations of the front and outſide, together with a ſection through the middle of the longeſt ſide, wherein the ſection of the roof is repreſented: As theſe figures are drawn on the ſame ſcale as thoſe in the former plate, and there is nothing material in them, but what the reader may underſtand, we ſhall not enlarge any further on ſo eaſy a ſubject.

The uſe of this building is to put under cover the carriages of guns, both for land and ſea ſervice, mortar-beds, pontoon-carriages, bread-waggons, ammunition-carts; in ſhort, all kind of carriages, that are uſed in artillery: and as wood laſts much longer in a place where there paſſes a free air, than if confined; it was for this reaſon, that the inſide walls have been built with arches, in the manner repreſented in the preceding figures.

Beſides the great ſtore-houſes in large fortreſſes, ſeveral ſmall ones are built in different places, not far from the ramparts, in order to lodge ammunition and other things neceſſary in a ſiege, ſo as to be near at hand; they are ſupplied from the great ones, when there is any occaſion for it: but as their conſtruction does not differ eſſentially from the former, excepting in their bigneſs, it would be needleſs to take any further notice of them.

The ſtore-houſes built in a maritime town, are not only to have room for artillery and ammunition, but likewiſe for cables, ropes, maſts, anchors, and every thing elſe, neceſſary in the fitting or repairing of ſhips; and this in proportion to the bigneſs of the harbour or number of ſhips that generally reſort there; theſe places ſhould have two ſtories, the lower for heavy things,

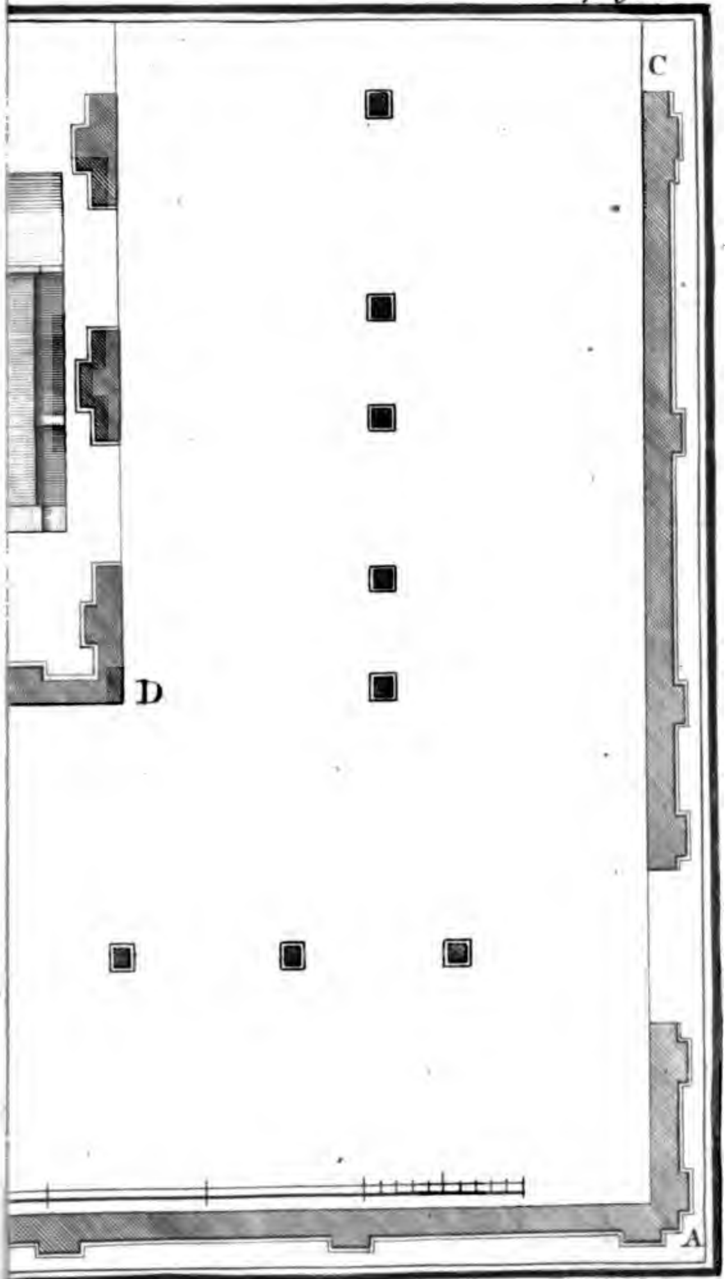

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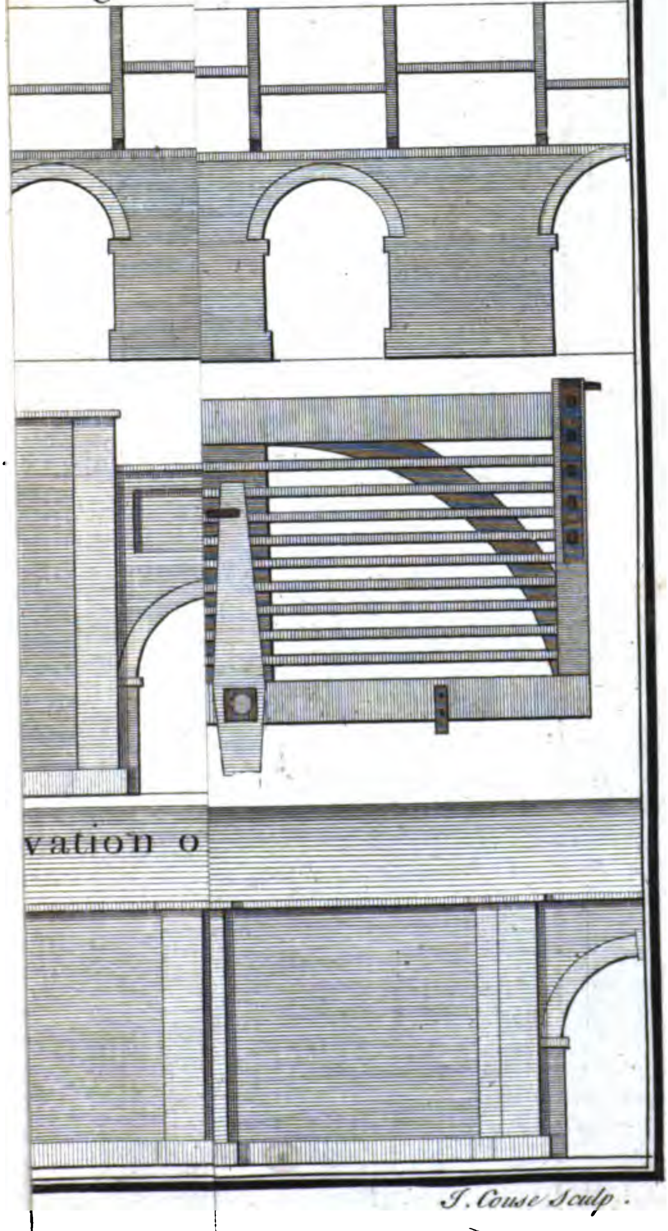
Plate XX.



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and the upper for thoſe goods that are light and manageable; their ſituation ought always to be near the harbour or quay, that the ſhips may come near them, whereby a great deal of labour may be ſaved, in the fetching and carrying things from them to the ſhips.

SECT. XXI.

Of framing TIMBERS *for* PARTITIONS, FLOORS *and* ROOFS.

AS an engineer ought not to be ignorant of any thing relating to common architecture, we think it will not altogether be unneceſſary, to ſhew here the different manners of framing timbers on moſt occaſions, this being a branch of his buſineſs, eſpecially as the carpenters follow no other rules than thoſe they learn from practice, which are often defective, as will appear hereafter.

Plate XXI. Here are five examples of different partition-frames; the firſt, ſecond, and fourth, are given by Mr. *Smith*; the third, and fifth, by Mr. *Price*; theſe are the only authors that wrote particularly upon this ſubject. The firſt example is in the common way, wherein it has been obſerved by an artiſt, that there are more mortiſes and tenons than need to be; for if the braces were let into the principal poſts, ſo as to butt againſt ſhoulders of about half an inch deep, and nailed in, they would do the ſame office in a better manner than being tenoned in, as here repreſented, and would be done in leſs than half the time: and as the quarters are only to ſuſtain the laths and plaſter; becauſe the weight of the roof being ſupported by the poſts and plates; they have no need of being framed into the upper and under plates, which only take up much time, and will not laſt longer than when they

are cut and nailed in only, and which is done in a very little time with little expence.

The example in the ſecond figure, repreſents the partition of a warehouſe, or of any other large building, where the girders, or ſome other weights are to reſt on the king or principal poſt, E; but it may be obſerved, that if this wall was to ſupport great weights in two places, it ſhould be inverted, ſo as the weights may reſt upon the poſts A, A: for in the firſt caſe, the two ſtruts adjoining to the poſt E, will increaſe its ſtrength very much, and in the latter, the ſtruts adjoining to the poſts A, A, will by the ſame reaſon, increaſe their ſtrength; but where the weight bears equally on the upper plate, this manner of ſtrutting is needleſs.' The author is alſo juſtly blamed for making the joggles in the king-poſts A, E, A, as being expenſive in the workmanſhip, and in the waſte of timber; it requires likewiſe much time in the framing of it; and after all, ſerves to no other purpoſe than the firſt example, which is full as ſtrong, and much cheaper.

The example repreſented by the fourth figure, is propoſed to raiſe the height of two ſtories, the lower of 13 feet, and the upper of 12, or otherwiſe in one height only, as the ſide of an outhouſe, hall, or ſaloon; now it is to be obſerved, that as joiſts are ſuppoſed to lie on the middle plate in the firſt caſe, which is framed into the king-poſts E E, and the outward principal poſts; the weight at each end muſt depend on the ſtrength of the tenons, excepting ſuch help as is given to it by the under quarters; the braces are therefore placed exactly the wrong way, becauſe now they ſupport the parts near the middle poſts which do not want it, whereas if their ends were turned the contrary way, they would aſſiſt the ends, as they ſhould do, as being the weakeſt part, and the whole would be equally ſtrong every where, and they would at the ſame time perform their office of bracing the frame in a proper manner.

As to the joggles at E, E, in the king-poſt, they are juſtly condemned by workmen here as well as in the firſt example, for the waſte of timber, and the loſs of time in framing; and it is thought, that if thoſe poſts were made a ſmall matter more in breadth, and their ſtruts let into them with a ſmall ſhoulder, commonly called by workmen, *bird's mouth*, they would be as ſtrong and ſecure as they can be done this way.

The next example in hand, is that repreſented by the third figure given by Mr. *Price*, which he ſuppoſes to be a partition between two rooms, wherein doors, A, A, are required next to the ends, and therefore has placed a king-poſt in the middle, and prick-poſts between it and the doors; it is here to be obſerved, that the middle plate, alſo called *intertie*, is halved, not only in the prick-poſts, but even into the king-poſt alſo, which is a great weakening to it, and therefore abſurd; nor indeed is there any occaſion for an intertie at all, if the height is intended for one ſtory only; but ſuppoſe there was one required, would not its being ſlightly tenoned into the king-poſt have been a leſs weakening to it, and have given it a ſtrong bearing, by turning the lower ſtruts the contrary way, to that they are here? It is true, that it is a common practice to halve timbers together, but it ſhould never be done but with very great judgment, and always avoided in braces and ſtruts.

The fifth figure, is another example given by Mr. *Price*, for a partition, wherein three doors are required, one at each end, and one in the middle; the two king-poſts and the intertie are again halved into each other; and therefore, the ſame fault may be found here as in the former: the joggles in the king-poſts and prick-poſts are likewiſe needleſs; beſides, the braces ſeem to have no other meaning here than to ſhorten the quarters which croſs them, and ſo are only nailed upon them here as well as in all the preceding examples, without tenons or mortiſes.

In all Mr. *Price's* examples of partition-walls, he ties the lower end of the king-poſts to the lower plate with an iron band, but for what reaſon, is not eaſy to be known, ſince, as far as I can judge, they ſeem to be entirely uſeleſs, and therefore ſhould never be uſed.

Many examples of partition-walls are given by authors, of different conſtructions, and for different uſes; but the whole art of framing this ſort of work, conſiſts in diſpoſing the different parts in ſuch a manner as to make the whole work equally ſtrong; in uſing no more timber than is neceſſary, and to join them ſo as that the work may be done in the ſhorteſt time poſſible, and yet be ſtrong and durable, which cannot be done without a competent knowledge of the rules deduced from mechanical principles, and a good deal of practice, which ſeldom both meet together; and for that reaſon, the art of building has received ſo little improvement in latter times.

SECT. XXII.

Of FLOORING.

Plate XXII. BEFORE a flooring is begun, there muſt be made an accurate plan of the building, whereby a judgment may be formed where to place the girders in the moſt ſubſtantial manner; and indeed, this ſhould be done before the brick-work is raiſed high enough to receive them, that not only the lintels may be well placed over the doors and windows; which ought never be leſs than 5 by 7 inches; but in thoſe places where the ends of the girders are to reſt, if the lintels or bearing pieces are made equal in length to the diſtance that is contained between girder and girder, they will communicate the weight equally on

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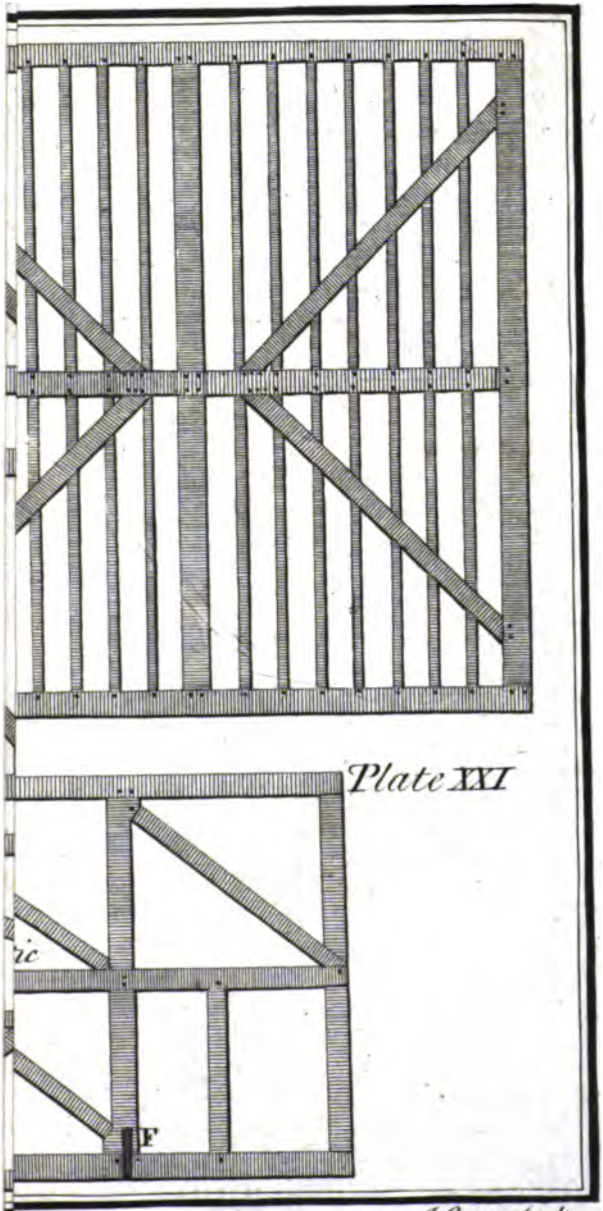

Plate XXI

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on the whole wall, and which is much better than when the bearing is on the part juſt underneath them only, which is the caſe when the lintels are made ſhorter; beſides, when lintels are ſo laid, and are 5, 6, or 7 inches in thickneſs, in proportion to that of the wall, they are a very great ſtrengthening, and tie thoſe parts very firmly together: wherefore they are alſo called *bond timbers*; but to prevent miſtakes, it muſt be obſerved, that bond timbers are properly thoſe laid in walls where no girders are, as in end and croſs-walls, and which are laid throughout at every 6 or 7 feet in height, and being dovetailed or cogged together at every outward angle of the building, as marked in figure 2, and at every party-wall, as in figure 3, or 4, will moſt firmly bind the whole together, ſo that, if even the foundation be bad, they oblige the whole building to ſettle together, prevent cracks and fractures, which unavoidably would happen, if they were neglected: It may be obſerved, that theſe three different ways of joining timbers are uſed, but the ſingle dovetail, as is marked in the fourth figure, is preferable to the other two, as being more ſimple, and yet tie the timbers full as well as the others.

The proper places for girders having been determined, it muſt be obſerved, to lay them ſo as the boards lay all one way throughout the middle of the building, ſo that the whole may be ſeen one way; for if the joints of the floor of one room are not parallel to thoſe of another, it would produce a very ill effect.

The ſituation of the girders being determined in the plan, we are thereby enabled to find their length, their number, and their diſtance, which ſhould never exceed 12 feet in any building whatſoever; nor ſhould joiſts exceed that length: It is alſo obſerved in placing of girders, always to lay them the ſhorteſt way, and that their ends have at leaſt 14 inches bearing in the wall, excepting thoſe in very ſmall buildings, where the walls are of thin dimenſions, then their bearing may be reduced to 10 inches.

Nothing being a greater enemy to timber than lime, it is a very good method to lay the ends of girders, lintels, and other bond-timbers in loam; and fir is beſt preſerved by anointing it over with melted pitch and greaſe, of which the laſt being one fifth part, and the other four fifths: If this precaution is neglected, which is commonly the caſe, the building will never laſt ſo long as it would otherwiſe do.

As the proper ſcantlings of girders and other timbers, have been treated of in the third ſection, where we have given tables of their dimenſions in reſpect to their length, we ſhall no farther enlarge upon it here; and having ſufficiently explained the ſituation and manner of laying girders, we ſhall now proceed to the joiſts, which are of various kinds, as common-joiſts, triming-joiſts, binding-joiſts, bridging joiſts, and cieling joiſts.

Common-joiſts are thoſe which are framed fluſh with the upper ſurface of the girders, and which ſometimes are all of equal depth, but leſs than that of the girders, whereby the girders become lower than the cieling; but the moſt genteel way is to have every third or fourth joiſt equal in depth with the girder, whilſt the other intermediate joiſts are of leſs depth, and between thoſe deep joiſts, fix ſmall ones to carry the cieling, whereby the under ſurface of the girders will be concealed, which otherwiſe have an ill effect.

Triming-joiſts are ſuch as are framed into two other joiſts, for other joiſts to be framed into them, which are againſt a chimney, or to make the opening for a ſtair-caſe, ſuch as are marked by the letter *a*: as theſe joiſts are weakened by receiving many mortiſes, and having to ſupport the weights of ſeveral joiſts which bear upon them; they are therefore to be made of larger ſcantlings than the common-joiſts.

Binding joiſts are thoſe on which bridging joiſts are laid, and in which the cieling joiſts are framed; theſe joiſts are framed fluſh with the under ſurface of the girders, and about 3 or 4 inches lower than the upper ſurface; that the cieling-joiſts may be fluſh underneath with them as well as with the girders: their diſtance is from 3 to 10 feet, and their thickneſs in proportion to the length of their bearing, as has been ſhewn in the third ſection.

The figures 8, 9, and 10, repreſent the manner in which their tenons and mortiſes are made by Mr. *Price*; and which is eſteemed by workmen in general much better than any other: but thoſe who are converſant with the principles of mechanics, will eaſily perceive that neither the one nor the other is good for any thing.

In order to determine the beſt manner of making the tenons, it is neceſſary to conſider, that when a great weight bears upon the middle of theſe joiſts, or upon any other timber ſupported at each end by tenons; it is evident, that it will bend a little, and the under part *x*, as in figure 8, will be the point fix; and therefore when the tenon is placed in the middle as here, the diſtance of the line of direction of the force which endeavours to break the joiſt, from the point fix *x*, is equal to half the height *x v*; but on the contrary, if the tenon is placed higher, that diſtance becomes greater; and of conſequence, the reſiſtance becomes greater, which ſhews that the nearer the tenon is to the upper part *v*, the greater the reſiſtance will be: But as the mortiſe muſt not be too cloſe to the upper edge, otherwiſe the tenon would break it; I think the beſt way is to divide the height *x v* into four equal parts, one of which is to be the thickneſs of the tenon, and placed two from the lower end *x*, and one from the upper *v*: as to the tenons marked in figures 9, and 10, they ought to be rejected as being contrary to the principles of mechanics. It is to be obſerved, that all binding-joiſts ought to be half as thick again as common joiſts; becauſe, they being weakened by mortiſes and having a greater weight to ſupport, it is neceſſary that they ſhould be ſtronger in proportion.

Bridgings or bridging-joiſts are repreſented by the letter *f*, in the firſt figure, lying on the binding-joiſts *d*, and which are alſo repreſented in figure 6, where *n*, *n*, repreſent the ſections of two binding-joiſts, and *d d*, a part of the length of a bridging-joiſt, and *f f*, that of a cieling-joiſt, with the manner of their reception by the binding-joiſts; the fifth figure is a ſection which ſhews the manner of fixing cieling-joiſts *c* between the deep joiſts *b*, *b*, where ſhallow ones as *a*, *a*, *a*, are framed in between them, as has been obſerved to be the moſt genteel way of framing common joiſts.

The diſtance of bridgings is generally about 12 to 14 inches, and their ſcantlings about 3 by 4 inches, or elſe 3.5 by 5, and their bearing is never more than the intervals of binding-joiſts, which is from 3 to 10 feet, as we have obſerved before, and which are laid even or fluſh with the girders to receive the boarding.

Cieling-joiſts, the moſt ſlender of all other kinds of joiſts, as having the leaſt weight to ſupport, are made about 2 by 3, or 3 by 4 inches, according to the ſtrength of the building; theſe are repreſented in the firſt figure by the letter *g*, whoſe diſtances are generally 12 or 14 inches: theſe joiſts are tenoned into the binding-joiſts, as is repreſented in figure 7, where *x* repreſents a ſingle mortiſe made on the one ſide of the binding-joiſt, and *r*, *s*, two double ones called *pulley-mortiſes*, in the ſide of a parallel binding-joiſt to receive the other end of the ceiling-joiſt. Theſe cieling and bridging-joiſts are ſeldom fixed till the building is covered in; when the laſt are pinned down to the binding-joiſts. Theſe kind of floors are called bridging-floors, and are the beſt ſort of carcaſe flooring.

Having ſhewn the manner of laying the ſeveral timbers for flooring, it remains now to ſhew how the floors themſelves are to be laid; their beauty depends on the colour and ſmoothneſs of the boards, without knots, and the cloſeneſs of the joints; for which reaſon, the carpenters plain the boards, and ſtraiten the edges ſometime before they are laid, in order that they may be ſufficiently dry, and not ſhrink afterwards.

As it is not an eaſy thing to find a ſufficient number of boards free from knots, the beſt are generally pick'd our for the floors of the principal apartments, and the reſt are uſed in other places leſs conſpicuous. It has been found by experience, that if the boards are ever ſo dry, and the edges are anew dreſſed, they will ſhrink again; for which reaſon, they never touch them after the firſt time: and the beſt way of making cloſe joints is not to nail down the boards, till a twelve month after they have been laid; this the workmen will not do unleſs they are obliged to it by agreement, under pretence that it is more work than they can afford to do.

The beſt wood for flooring in this country is the fine clear yellow deal well ſeaſoned, which when well laid keeps its colour a great while; whereas the white ſort becomes black by often waſhing, and looks very bad. In buildings of conſequence the ſappy part is cut off, and nothing but the heart is uſed, but then theſe floors are very expenſive. But in common buildings, which are made by contract, they ſeldom make even uſe of dry ſtuff, unleſs it is particularly mentioned in the agreement.

The joints of the boards are commonly made plain, ſo as to touch each other only; but when the ſtuff is not quite dry, and the boards ſhrink, the water runs through them when the floor is waſhed, and ſpoils the cieling underneath; for which reaſon, they often make feather edges in better buildings, ſo as to cover each other of about half an inch; and ſometimes they are made with groves and tenants; this laſt method, when well executed, appears to me preferable to any other whatſoever.

I am informed, that in the beſt buildings, the joints are made with dove tails; then the lower edge is nailed down, and the next drove into it, by which the nails are concealed, which certainly makes the floor look much handſomer than when the nails are ſeen: for when they are waſhed the nails grows ruſty, and appear like ſo many blacks ſpots upon the floor, which has an ill effect.

The manner of meaſuring floors is by ſquares of 10 feet each ſide; ſo that taking the length and breadth in feet, and multiplying them together; then by ſtriking off the two laſt figures as decimals, the remainder will be the content expreſſed by theſe ſquares. Thus a floor of 18 feet by 16, gives 288 ſquare feet, or 2 ſquares and 88 decimal parts; ſo that if the price of a ſquare of flooring is known, that of the whole will be eaſily found by proportion.

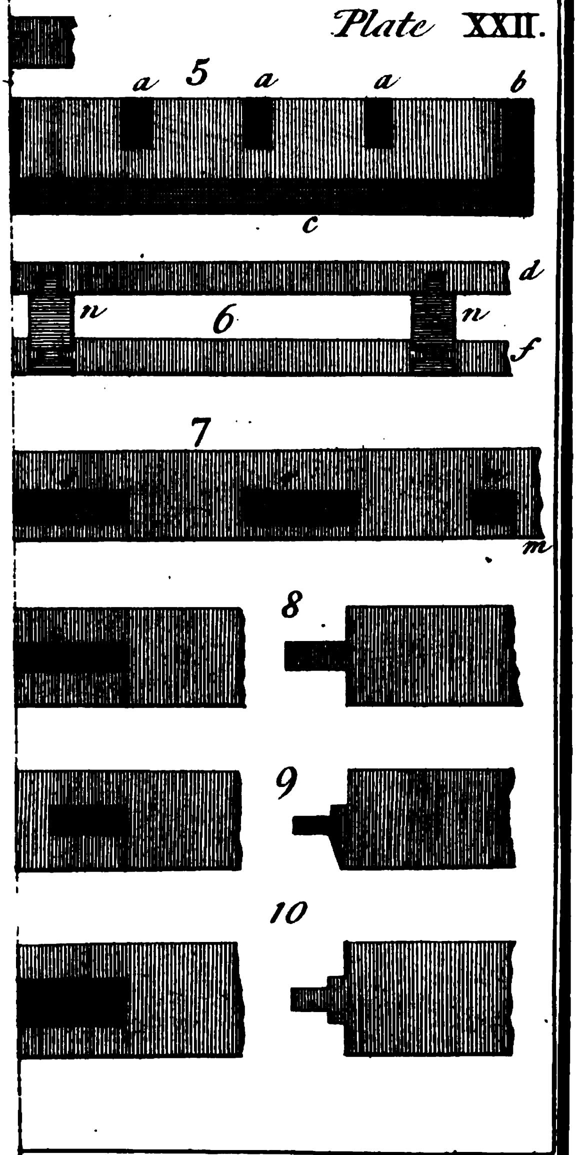
Formerly oaken boards were uſed for flooring, but at preſent they are neglected, excepting upon ſome particular occaſions, as in cloſets and other private rooms: theſe boards are framed together with pannels, like doors, and poliſhed with wax, which makes them look very beautiful, and are agreeable to thoſe who diſlike a wet room; but as they are ſlippery, and very expenſive, they are much out of faſhion.

SECT. XXIII.

Of ROOFINGS.

Plate XXIII. WE are now come to the formation of roofs, of which the former wall plates are a part, as being the baſe on which the ſmall rafters ſtand. We muſt, after having formed it, according to the plan of the building, and ſecured its angles, in

Plate XXII.



J. Couse Sculp

UNIV. OF MICH.

in the manner repreſented in the ſecond figure, plate XXII. conſider the proper diſtances and places to lay the beams on; where it muſt be obſerved, 1. To avoid the joints of the plate: 2. That their diſtances be not too great, leſt you are obliged to have large cieling-joiſts, and large purlins, which are but a load to a building, and therefore ſhould not exceed ten feet. 3. That they lay over, or nearly over, the heads of the principal poſts, in timber building, and on the middle of the piers, when they are of brick or ſtone.

The ſituation and length of the tie-beams being determined, their under ſurface at each end being equal to the breadth of the wall-plate, is dovetailed an inch and a half or two in depth, according to their ſtrength, and which are let into both theſe plates, in the manner repreſented by the third and fourth figures, plate XXII; but as it has been ſhewn already with a ſingle dovetail, as in figure 4. If the breadth be divided into three equal parts, make the narrow part of the dovetail one; which to the end opens to the whole breadth of the beam. When the tie-beams are thus dove-tailed into the plates, they are then ſaid by the workmen to be cogged down, and ready to receive the cieling-joiſts, and principal rafters.

But before the principal rafters can be framed, the height of the pitch, and their length muſt be determined; the pitch of every roof ought to be made according to its covering; which is of lead, pantiles, plaintiles, or ſlates; theſe are all the different coverings uſed in *England*. The uſual pitches are the pediment-pitch, common pitch, generally called true pitch, and the gothic pitch.

Pediment pitch is that whoſe perpendicular height is equal to two ninths of the breadth of the building; becauſe the height of a pediment is likewiſe two ninths of its baſe; this pitch is uſed when the covering is lead. Common pitch is that whoſe rafters are the three fourths in length of the breadth of the building; when it ſpans the building all at once; but is oftner divided into two equal pitches; and it is uſed when the covering is of plaintiles.

Gothic pitch, is that when the length of the principal rafters is equal to the breadth of the building, and therefore is equilateral; this pitch is uſed when the covering is of pantiles; ſome workmen would have the breadth of the building divided into ſeven equal parts, the perpendicular height to have two of them, and the length of the rafters to be four; and that this pitch may ſerve for coverings of lead or pantiles: on the contrary, others will have the perpendicular height to be one fourth of the breadth, when the covering is lead, which is ſomething leſs than what has been aſſigned above for that covering

That the perpendicular height ſhould be the three eighths of the breadth in pantiles covering, which is widely different from the former; or that the perpendicular height may be found by deſcribing an arc from the extremity with a radius of two thirds of the breadth of the building. Laſtly, the perpendicular height to be equal to half the breadth for plain-tiles covering, which makes the rafters ſomewhat ſhorter than in the pitch given before for that covering; and the length of the rafters to be five ſeventh parts of the breadth of the building for ſlate coverings, which is therefore nearly the ſame pitch as that for plain-tiles covering.

Theſe are the various pitches commonly uſed for the different coverings, and ſeem to depend chiefly on the builder's fancy. As regard is to be had to make the perpendicular height and length of the rafters, ſo as to be expreſſed by rational numbers, which is a great eaſe to the workmen, in that they may be traced with rulers and compaſſes; for which reaſon, the following pitch may be uſed when the covering is of lead or pantiels: Divide the breadth of the building into ſix equal parts, and make the perpendicular equal to four of them; then will the length of the rafters be five again.

Theſe pitches being a medium between thoſe given above, and the parts expreſſed by rational numbers, muſt certainly be better than any others whatſoever: to ſhew that theſe parts form a right angled triangle; we are to conſider that in a right angled triangle the ſquare of the hypothenuſe (which is the length of the rafters) 5 is equal to the ſum of the ſquares of the other two ſides, which are 3 and 4.

Altho' the principal rafters are commonly made equally ſtrong every where, yet ſome think that if they were at their feet nearly as thick as the breadth of the tie-beams, and to grow leſs towards the upper end, by one ſixth part, they would be better; which is certainly true, becauſe their centers of gravity become nearer to the point of ſupport; they require leſs timber; and as the rafters may as well be ſawed in this manner as in the uſual way; I ſee no reaſon why this method ſhould not be uſed.

The king-poſts ſhould be as thick as the tops of the principal rafters, otherwiſe they will not be able to receive them; and their breadth of ſufficient ſtrength to receive the ſtruts that are deſigned to be framed into them. Some will have it that the ſtruts ſhould diminiſh upwards as well as the rafters; but this would be carrying niceties farther than is neceſſary; when the lower ends of the rafters are ſtrongeſt, the purlins, collar-beams, and ſtruts, ſhould be placed ſomething higher than the middle of the rafters, that the bearings may be proportional to the ſtrength, and not in equal parts, as is uſual.

Purlins muſt have the ſame thickneſs as that part of the principal rafters to which they are framed, and their breadth is generally made to their thickneſs, as 4 to 3; therefore the breadth being 8, the thickneſs muſt be 6: tho' this is the rule carpenters go by, yet their dimenſions ought to be determined by the rules given in the third ſection, part I.

Purlins are generally framed into the principal rafters; but in my opinion, they ſhould rather be laid in the collar-beams, becauſe the rafters are not ſo much weakened by mortiſes, and the ſtrength of the purlins will then not depend on the tenons: when they are framed into the principal rafters, their length cannot be more than the diſtance between two contiguous rafters, which is from 10 to 12 feet only; but when they are laid in the collar-beams, they may then be twice or thrice that length, according as the ſtrength of the ſtuff will allow.

Small rafters may be in their ſcantlings 4 inches by 2.5, or 4.5 by 3.5, or elſe 5 by 3.5, according to the nature and ſtrength of the principals, and their length in a purlined roof ſhould not exceed ſeven feet: it is beſt to frame two rows of purlins, when the principal rafters are very long, in the manner repreſented in the firſt figure, plate XXIII. by the letters A, A; which figure repreſents the roof, as a plain ſurface; but the method of framing the purlins in a right line, as here repreſented, is not to be recommended; becauſe when the mortiſes in the principal rafters are againſt one another, they are not only weakened very greatly in thoſe parts, but you loſe the pinning alſo, and therefore they ſhould be framed, as repreſented by the letter B in the ſame figure.

The uſe of this figure is, to determine the number and ſituation of the principal ſmall and jack rafters; the principal rafters are thoſe marked by the letter D, and lie through the body of the plan, with tenons repreſented in the middle; the ſmall rafters are thoſe marked *f*, between the principals and the jack-rafters thoſe ſhort ones, whoſe tops bear againſt the hip-rafters C, and are marked by the letter E; the purlins are marked by the letters A and B; as to the other parts of a roof which cannot be ſeen in this figure, they are repreſented in the following ſection.

Fig. 2. This figure repreſents the ſection of a large roof, having a king-poſt and two ſtruts to ſupport the principal rafters, the tie-beam is ſuppoſed to reſt in the middle upon ſome party or partition-wall, otherwiſe that beam would not be able to ſupport the roof; becauſe the greateſt weight which is under the king-poſt, would reſt upon the weakeſt part, as has been ſhewn in the third ſection, part I.

Fig. 3. This figure is the ſection of a roof to be covered with pantiles; the length of the rafters is the two thirds of the breadth of the building, and the height one half; there is a lodging-room made in the middle; this roof is very ſtrong, and may ſerve almoſt in any building, eſpecially if the tie-beam is ſupported in the middle by a party-wall.

Fig. 4. This figure repreſents a roof, whoſe perpendicular height is three eighths, and the length of the rafters five eighths of the breadth; this roof is alſo very ſtrong; but I think that in ſmall buildings the king-poſts with its two ſtruts might be left out without any inconveniency; becauſe the two prick-poſts together with their ſtruts are ſufficient to ſupport the rafters.

Fig. 5. This figure is a ſection of a roof of pediment-pitch, with a valley in the middle to take off the barn roof aſpect, which it otherwiſe would have, if the rafters were continued up to an angle; in this roof are made two lodging-rooms, as being framed with a collar-beam, and middle-poſt, which laſt muſt be ſupported by a party-wall, otherwiſe the tie-beam will ſcarcely be able to ſupport the weight upon it, without its being of very large dimenſions.

It may be obſerved, that the poſts in fig. 2, 3 and 4, have all joggles, which are by many workmen not approved of, on account of the waſte of timber, and the length of time to frame them; in order to ſatisfy thoſe that are for plain-work, and yet make it ſtrong and durable, it will be ſufficient to cut the tenons of the ſtruts which enter into theſe joggles, as well as the mortiſes, in the ſame manner as they are repreſented here by the joggles, which will do very near as well; for all tenons cut at right angles will bear the preſſure of the poſts in the ſtrongeſt manner that can be. It muſt likewiſe be obſerved, that all the iron bands repreſented in theſe roofs, are thought by the workmen to be very uſeful in ſtrengthening the work, though needleſs in my opinion.

As workmen differ very much in their manner of framing roofs; it is impoſſible to give ſuch rules as will ſatisfy every body; but what has here been ſaid, together with the principles given in the third ſection, part I. of the ſtrength of different ſcantlings, will be ſufficient to the intelligent reader, to frame all ſorts of plain roofs, upon any occaſion, in the beſt manner, which is all we propoſe in this work: As to thoſe called manſard, or broken roofs, and thoſe for domes or cupolas, which are the moſt difficult of all carpenters work, their conſtruction rather belongs to a compleat architect than to an engineer.

But before we conclude this ſection, it will not be unneceſſary to ſhew how the length and poſition of the hip-rafters C, C, figure 1, are to be found; the diſtance P Q of the laſt principal rafter D from the end P of the roof is always equal to half the breadth P S of the building; and having the length Q R of the principal rafter D, that of the hip-rafter P R is likewiſe given, as being the hypothenuſe of a right angled triangle P Q R.

And becauſe the perpendicular height of the roof is given as well as the diagonal drawn from the point P to the foot of the perpendicular dropt from the point R to the plan of the building; the inclination of the hip-rafter C, may be found by a ruler and compaſſes; or by trigonometry, thus; The length of the hip-rafter PR is to the perpendicular height of the roof, as the radius is to the tangent of the angle made by this rafter, and the plan of the building.

Of CEILING.

Although the manner of ceiling is very common, yet it is neceſſary, that the young engineer ſhould know how it is performed: In buildings of no great conſequence, the laths are nailed on the joiſts, ſo as a part of the girder appears below the ceiling; this is done in view to get 5 or 6 inches in the height of the room; and the part of the girders that appear are covered with deal boards, with a little cornice round it, and painted with the ſame colour as the wainſcot. The plaiſter for ceiling is made of lime and hair, to make it ſtick the better, and laid on very ſmooth; when it is dry and has any cracks in it, as commonly happens, it is paſſed over with a trowel dipt in thin plaiſter, this is continued till it is quite ſmooth, and without any cracks; after this it is white-waſhed two or three times over, with lime-water and ſize, till it appears of a fine white.

But in buildings of any conſequence, ceiling-joiſts are framed into the girders, ſo as to be even with the under ſurface, as has been obſerved before: As theſe joiſts are put in after the frame of the floor is made, and juſt before the ceiling is finiſhed; one of the mortiſes is made about a foot long, ſloping ſo as that when the tenant at one end is fixt into the mortiſe, the other may ſlide through the other till it becomes perpendicular to the girder where it is pinned down.

As to ceilings made with various work, or that are painted, the curious reader may conſult books of architecture, which treat of them; we ſhall only add, that ceilings are meaſured by the yard of 9 feet ſquare.

Of WAINSCOTING.

Formerly wainſcoting was made with oak, and it is from thence it has derived its name, but at preſent

Pan-tiles are of a quadrangular figure, when flat of about 13 inches long, 6 or 7 inches broad; they are bent croſs-ways in the form of an S, only one of the arches is about three times as big as the other; ſo that when they are laid on a roof, one of the edges which is leaſt bent is covered by the edge of the other that is moſt bent, ſo that the roof looks like furrows, one high and the other low; theſe tiles ſerve moſtly for low roofs, ſuch as ſtables, ſheds, and outhouſes; about 600 will cover 100 feet ſquare.

Ridge-tiles are uſed to cover the ridges of houſes, and are made in the form of a ſemi-cylindric ſurface, of about 13 inches in length, and of the ſame thickneſs as plain-tiles; their breadth at the outſide meaſures about 16 inches or leſs.

Hip, or corner-tiles, are at firſt made flat like plain-tiles of a quadrangular figure, whoſe two ſides are right lines, and the ends arcs of circles; the upper end concave, and the lower convex, the latter being about ſeven times as broad as the other; they are about 10.5 long, but before they are burnt are bent upon a mould in the form of a ridge-tile, and have a hole at the narrow end to nail them on the hip-corner of the roof.

Gutter-tiles are made like corner-tiles, only the edges at the larger ends are turned up for about four inches: theſe tiles are ſeldom uſed where lead is to be had, as being better for this purpoſe.

Dutch-tiles are commonly uſed in chimnies; they are made of a whitiſh earth, glazed and painted with various figures, ſuch as birds, flowers, or landſkips, in blue or purple colour; and are about 6.5 inches each way, and three quarters of an inch thick: when theſe tiles are properly ſet with good mortar, they look very beautiful, and caſt a greater heat than ſtone; for being very ſmooth, and glazed, the rays of heat ſtriking upon them are all reflected backward into the room, eſpecially when the ſides of the chimnies are oblique, or in the form of circular arcs.

Pan-tiles are laid in mortar, becauſe the roof being very flat, and many tiles being warpt in the burning, they will not cover the roof ſo well as that no water can paſs between them. Sometimes theſe tiles are varniſhed with a dark brown colour; which makes them laſt a great while, and look better than the others, but are dearer in proportion.

Plain-tiles are not laid in mortar, but pointed only in the inſide; as to the ridge and corner-tiles they are all laid in mortar, becauſe they lie ſeldom ſo cloſe, as not to admit any water to paſs between them. There are alſo uſed tiles in paving, that are either ſquare or hexagonal, which when well burnt and laid in good mortar look very neat, and laſt long; but as paving in general is ſo well known, it would be needleſs to ſay any more about it.

PART IV.

Of AQUATIC BUILDINGS.

AS theſe kind of works contain a greater variety than thoſe conſtructed on dry land, and require much more ſkill and knowledge both of the theory and practice; no leſſer work than Mr. *Belidor's* Architecture Hydraulic, is neceſſary to give a true knowledge of their conſtruction, and execution, according to the different ſituations and circumſtances; As this author had the Aſſiſtance of the greateſt engineers in *France*, who have more experience, and knowledge both in theory and practice, than any others in *Europe*; ſo no man had a better opportunity to give every thing neceſſary relating to this ſubject. Since therefore his works are, or ought to be, in the hands of every engineer, we ſhall content ourſelves, to give here ſome general principles, together with particular obſervations of the moſt material parts of theſe buildings, for the ſake of thoſe, who have no oportunity to peruſe ſo extenſive a work as his.

SECT. I.

Of STONE-BRIDGES.

THE ſituations of bridges is eaſily known, and need no explanation; the only thing to be obſerved is, to make them croſs the ſtream at right angles, for the ſake of the boats that paſs through the arches, with the current of the river; and to prevent the continual ſtriking of the ſtream againſt the piers, which may endanger them in a long courſe to be damaged and deſtroyed in the end.

Bridges built for a communication of high roads, ought to be ſo ſtrong and ſubſtantial as to be proof againſt all accidents that may happen, to have a free entrance for carriages, afford an eaſy paſſage to the waters, and be properly adapted for navigation, if the river admits of it; therefore the bridge ought to be at leaſt as long as the river is wide in the time of its greateſt flood; becauſe the ſloping of the water above may cauſe too great a fall, which would prove dangerous to the veſſels, and occaſion the under graveling the foundation of the piers, and abuttments.

To this may be added, by reducing the paſſage of the water too much, in time of a great flood, it might break through the banks of the river, and overflow the adjacent country, which would cauſe very great damages; or, if this ſhould not happen, the water might riſe above the arches, and endanger the bridge to be overſet, as it has happened in many places.

When the length of the bridge is equal to the breadth of the river, which is commonly the caſe, the current is leſſened by the ſpace taken up by the piers, for which reaſon, this thickneſs ſhould be no more than is neceſſary to ſupport the arches; and it depends, as well as that of the abuttments, on the width of the arches, their thickneſs, and the height of the piers.

The form of the arch is commonly ſemi-circular; but when they are of any great width they are made elliptical, becauſe they would otherwiſe become too high; as has been done at the *Pont Royal*, at *Paris*, where the middle arch is 75 feet, and its height would have been 37.5 feet, inſtead of which, it is only 24 by being made elliptical.

Another advantage of much more importance ariſes from the oval figure, which is, the quantity of maſonry of the arches is reduced in the ſame proportion as the radius of the arch is to its height. That is, if the radius is 36 feet, and the height of the arch 24, that is three fourths of the radius, the quantity of maſonry of the arches is likewiſe reduced to three fourths; which muſt leſſen the expence of the bridge conſiderably.

When the height of the piers is about ſix feet, and the arches are circular, experience has ſhewn, ſays Mr. *Belidor*, it is ſufficient to make the thickneſs of the piers the ſixth part of the width of the arch, and two feet more; that is, the thickneſs of the piers of an arch of 36 feet, ought to be 8 feet; thoſe of an arch of 48 feet, to be 10.

When the arches become of a great width, the thickneſs of the piers may be reduced to the ſixth part of that width; but the depreſſion of the two feet is not done at once; that is, in an arch of above 48 feet, 3 inches are taken off for every ſix feet of increaſe of the width of the arch. For inſtance, the thickneſs of the piers ſupporting an arch of 72 feet wide, ſhould be 14 feet, according to the preceding rule; but by taking off 3 inches for every 6 feet, above an arch of 48 feet wide, the thickneſs of the piers is reduced to 13 feet: Conſequently, by following the ſame rule, the thickneſs of the piers ſupporting an arch of 16 fathoms wide, will be 16 feet; all the others above that width are the ſixth part of the width.

After this, Mr. *Belidor* gives a rule for finding the thickneſs of the piers which ſupport elliptic arches, and makes them ſtronger than the former: The abuttments he makes one ſixth part more than the piers of the largeſt arch.

It is plain, that theſe rules are merely gueſs-work, determined from ſome works that have been executed. But tho' examples are neceſſary to confirm the truth of the theory, yet they are not ſufficient to form, from one or two bridges that have been built, a general rule for others of different forms or dimenſions, without either making ſome ſtronger or weaker than they ought to be; beſides, granting this rule to be true, yet when the piers are of any other height, we are quite left in the dark; and therefore, it is neceſſary to have recourſe to theory, in order to find how much the piers are to vary in their thickneſs, according to their height, and the width of the arches: But previous to this theory, it is neceſſary to know, the proper thickneſs of the arches at their key-ſtones, becauſe that of the piers depends partly on it.

The thickneſs of the arch-ſtones, I muſt confeſs, is not to be determined by theory, at leaſt that I know of; nor do thoſe authors who have written on the ſubject agree amongſt themſelves; Mr. *Gautier*, an experienced engineer, in his works, makes the length of the arch-ſtones, of an arch 24 feet wide, 2 feet; of an arch 45, 60, 75, 90 wide, to be 3, 4, 5, 6 feet long reſpectively; when they are hard and durable, and ſomething longer when they are of a ſoft nature; on the contrary, Mr. *Belidor* ſays they ought to be always one twenty fourth part of the width of the arch, whether the ſtone be hard or ſoft; becauſe, if they are ſoft, they weigh not ſo much.

But that the length of the arch-ſtones ſhould be but a foot in an arch of 24 feet wide, 2, 3, 4, in arches of 48, 72, 96, feet, it appears to me impoſſible; becauſe the great weight of the arches would, as I imagine, cruſh them to pieces, by the preſſure againſt one another; and therefore Mr. *Gautier's* rule ſeems to be much preferable: As he made the length of the arch-ſtones to increaſe in a ſlower proportion, from 10 to 45 feet wide, than in thoſe above that width; we imagine, that the latter will be ſufficient for all widths, whether they are great or little: Therefore in the following computation, we ſhall ſuppoſe the length of the arch-ſtones of 30 feet in width to be two feet, and to increaſe one foot in fifteen, that is, 3 feet in an arch of 45 feet, 4, 5, 6, in an arch of 60, 75, and 90 feet;

and ſo the reſt in the ſame proportion; this being premiſed, we ſhall proceed to ſhew how the thickneſs of the piers is to be found.

PROBLEM.

Plate XXIV. Fig. 4. *To find the thickneſs* B C *of the piers, when the arch is terminated by two concentric ſemi-circles, and there is a wall* R N *above the middle of the piers whoſe height is equal to that of the arch, and its baſe to the difference between the breadth* A D *of the pier, and twice the thickneſs* A G *of the arch.*

Let the radius O M paſs through the center of gravity L of half the arch G E, L K, and L I, perpendicular to O A and O L; then if the radius O A of the interior circle be called a, the radius O G of the exterior one b; their difference A G, d; O K or K L $= m$, n the area G E of half the arch; the height A B of the piers c, their thickneſs B C $= z$; laſtly, let unity be to r, as the radius is to the ſemi-circumference; or, which is the ſame, let $r = 3.142$ nearly, then by what has been ſaid in the ſecond problem, ſection II. of the firſt part; we have $4n = rbb - raa$, $\frac{3r}{4}m = a + \frac{bb}{a+b}$, $g = c + 2m - a$, and $2ng - 2nz$ for double the momentum of the arch's preſſure againſt the pier.

Now becauſe the baſe R G of the wall above the pier is equal to A D − 2 A G, or $z - 2d$, and its height R N $= b$, $bz - 2bd$ will expreſs the area of that wall, and as the line which paſſes through its center of gravity perpendicular to B C biſects that line; $\frac{1}{2}z$ will be its diſtance from the point fix C; we have $\frac{1}{2}bzz - bdz$ for its momentum; and as the momentum

tum of the pier C A, has been found in the above cited problem to be $\frac{1}{2}czz$; double the ſum of theſe two laſt momentums being made equal to $2ng - 2nz$, gives $bzz + czz - 2bdz = 2ng - 2nz$; or if we ſuppoſe $b + c = s$, and $n - bd = sq$; this equation becomes $szz + 2sqz = 2ng$; whoſe ſquare root is $z + q = \sqrt{\frac{2}{s}ng + qq}$.

REMARK.

We have ſhewn in the ſecond ſection of the firſt part, after problem the ſecond, that on account of the cement and roughneſs of the ſtones, the weight of the arch, or, which is the ſame, the area n of G E, ſhould be diminiſhed by one third or more, in order to have the true momentum of the arch; and as in bridges, the parts between the arches are filled up with looſe ſtones, their weight will be greater in this caſe, than it would be otherwiſe; The queſtion is therefore to find what value ought to be aſſigned for n, in order to find the thickneſs of the piers able to ſupport the preſſure of the arch, when it is loaded with this additional weight. For ſince the ſpaces above the arches are always ſimilar when the upper part of the bridge is horizontal, and conſequently proportional to the ſimilar parts A G F E, and this is nearly ſo in bridges; it is manifeſt, that if the whole area A G F E, is taken for the value of n, and the piers are ſufficiently ſtrong in one caſe, it will be ſo in all others.

As the value of n cannot be eſtimated ſo truly as from ſome bridge that has been executed, and is looked upon by the maſters of this art, as a model to go by; ſo we ſhall make it appear, that if n expreſſes the whole area A G F E; the thickneſs of the piers will come out nearly the ſame as thoſe of the *Pont Royal* at *Paris*, which ſupport the greateſt arch.

According to Mr. *Belidor*, in an arch of 75 feet wide, the thickneſs of the piers whoſe height is about 6 feet, ſhould be 13.5, when the arch is circular; and 15 feet when it is elliptical, as that of the abovementioned bridges; But we have ſhewn in the ſecond ſection, that the preſſure of an elliptic arch is no greater than that of a circular form, on account of the weight being leſs in the former than in the latter; and ſince according to the problem above, the thickneſs of the piers of ſuch an arch, is found to be 14 feet, when they are 6 feet high, as in thoſe of the *Pont Royal*; it is evident, that the value of *n* aſſumed here, agrees with the above rule as nearly as can be expected.

Now as Mr. *Belidor* ſays, that his rules are agreeable to the practice of the greateſt maſters in that branch of engineering, we may preſume, that the thickneſſes of the piers, we have found, will be ſufficient in all the different caſes that can happen, with this precaution however, that the piers are made of ſtrong ſolid ſtones, laid in the beſt and moſt ſubſtantial manner.

It is to be obſerved, that the thickneſs of the piers here found, are ſuch as if there were but one ſingle arch; but when there are arches on each ſide, the preſſure of the one deſtroys that of the other; but as all the arches cannot be built together, it is of abſolute neceſſity, that the piers ſhould be able to reſiſt the preſſure of each arch, independent of the adjacent ones; for which reaſon, it is neceſſary to build the wall GN above the pier before the arches are formed, as Mr. *Labely* has moſt judiciouſly done at *Weſtminſter-bridge*; for by this means, the arch will be in no danger to fall and cauſe needleſs expences. As to the parts between the arches, and the wall G N, they ought not to be filled up till ſuch time as the arches on each ſide are finiſhed.

TABLE containing the thickneſs of the piers of BRIDGES.

	6	9	12	15	18	21	24
20	4.574	4.918	5.165	5.350	5.492	5.610	5.698
25	5.490	5.913	6.216	6.455	6.645	6.801	7.930
30	6.386	6.816	7.225	7.513	7.746	7.939	8.102
35	7.258	7.786	8:200	8.532	8.807	9.037	9.243
40	8.404	8.691	9.148	9.523	9.835	10.101	10.328
45	8.965	9.579	10.077	10.489	10.837	11.136	11.394
50	9.805	10.454	10 987	11.435	11.817	12.146	12.434
55	10.640	11.245	11.882	12.364	13.019	13.149	13.218
60	11.400	12.110	12.718	13.281	13.723	14.109	14.314
65	12.265	13,025	13.648	14.185	14.654	15.082	15.433
70	13.114	13.869	14.517	14.049	15.573	6.011	16.400
75	14.000	14.705	15.346	15.965	16.480	16.940	17.354
80	14.747	15.542	16.234	16.842	17.381	17.864	18.298
85	15.513	16.328	17.041	17.674	18.237	18.742	19.198
90	16.373	17.201	17.929	18.578	19.157	19.679	20.152
95	17.184	17.826	18.772	19.438	20.036	20.577	21.068
100	17.991	18.848	19.610	20.293	20.908	21.460	21.976

The firſt horizontal line expreſſes the height of the piers in feet, from 6 to 24 feet, each increaſing by 3: the firſt vertical column, the width of arches from 20 to 100 feet, for every 5 feet.

The other columns expreſs the thickneſs of piers in feet and decimals, according to the reſpective height at the head of the column, and the width of the arch againſt it in the firſt column.

Thus for example, let the width of the arch be 60 feet, and the height of the piers 12; then the number 12.718, under 12, and againſt 60, expreſſes the thickneſs of the piers, that is 12 feet, and 8.6 inches; we muſt obſerve again, that the length of the key-ſtone is 2 feet in an arch of 30 feet wide; 3, 4, 5, 6, in an arch of 45, 60, 75, 90; that of 20 feet wide one foot 4 inches; and the length of any other width is found by adding 4 inches for every five feet in width.

As this table contains the thickneſſes of piers in reſpect to arches that are commonly uſed in practice, we imagined, that to carry it farther would be needleſs; beſides, if any other arch of a greater width was propoſed, the ſtrength of its piers may be found by the foregoing problem, as well as that of any intermediate one not inſerted here; or becauſe the difference between the thickneſs of the piers of any two contiguous arches is but ſmall; thoſe between any two marked here, may be made equal to half the ſum of the next below and above it: thus the thickneſs of the piers of an arch 52 or 53 feet wide is nearly equal to 10.222, half the ſum of the thickneſſes 9.805 and 10.64 of the arches 50 and 55 feet wide, when the height of the piers is 6 feet.

Rectangular piers are ſeldom uſed but in bridges over ſmall rivers; in all others, they project the bridge by a triangular priſm, which preſents an edge to the ſtream, in order to divide the water more eaſily, and to prevent the ice from ſheltering there, as well as veſſels from running foul againſt them; that edge is terminated by the adjacent ſurfaces at right angles to each other at *Weſtminſter* bridge, and make an acute angle at the *Pont Royal*, of about 60 degrees; but latterly the *French* terminate this angle by two cylindric ſurfaces, whoſe baſes are arcs of 60 degrees, in all their new bridges.

When the banks of the rivers are pretty high, the bridge is made quite level above, and all the arches of an equal width; but where they are low, or for the ſake of navigation a large arch is made in the middle of the ſtream, then the bridge is made higher in the middle than at the ends; in this caſe, the ſlope muſt be made eaſy and gradual on both ſides, ſo as to form above one continued curve line, otherwiſe it appears diſagreeable to the eye. Mr. *Belidor* will have the deſcent of that ſlope to be one twenty fourth part of the length; and Mr. *Labely* ſays he made it one twentieth part only, which he thinks to be ſcarce perceptible; but as *Weſtminſter* bridge is 1220 feet according to his own account; if half this breadth be divided by 20, we ſhall find 30.5 for the difference between the height of the middle arch and the end of the abutments: now if this can be called ſcarcely perceptible, I ſhould be glad to know how far this deſcent may be carried, ſince it is plain, that the ſlope of *Weſtminſter* bridge is too much by a good deal, according to the beſt judges; for the beauty of any bridge conſiſts, in that one may ſee from one end to the other, like a ſtreet, if it is poſſible; or, if the nature of the ſituation does not permit it, the leaſt riſing is the beſt; for which reaſon, I ſhould think that one fiftieth part of the length is quite ſufficient for the deſcent; whence, according to this rule, the middle arch of the above mentioned bridge would be about 11 feet higher than the ends of the abutment, which, in my opinion, would have looked very well.

It may be ſaid, that the circumſtances would not allow ſo eaſy an aſcent, becauſe the arches are circular; but if the middle arch, which is 38 feet high, had been made elliptical, then that height would have been reduced to 28.5 feet, that is, to three fourths of the preſent height; this would have diminiſhed the height of the bridge by 9.5; and beſides one fourth of the maſonry contained in the arches would thereby have been ſaved, which methinks would have been a ſufficient inducement to recompence the little more trouble required to make an elliptic arch inſtead of a circular one.

The width commonly allowed to ſmall bridges is 30 feet; but in large ones near great towns, theſe 30 feet are allowed clear for horſes and carriages, beſides a banquet at each ſide for foot paſſengers of 6 to 9 feet each, raiſed about a foot above the common road; the parapet-walls on each ſide are about 18 inches thick, and 4 feet high; they generally project the bridge with a corniſh underneath; ſometimes balluſtrades of ſtone or iron are placed upon the parapet as at *Weſtminſter*; but this is only practiſed where a bridge of a great length is made near the capital of a country.

The ends of bridges open from the middle of the two large arches with two wings making an angle of 45 degrees with the reſt, in order to make their entrance more free and eaſy; theſe wings are ſupported by the ſame arches of the bridge next to them being continued in the manner of an arch, of which one pier is much longer than the other.

We have before determined the length of the key-ſtone, but ſaid nothing of the others towards the ſpring of the arch; which were formerly made all of the ſame length, and the reſt of the front-walls finiſhed with horizontal courſes up to the cordon, and the ſpandrels or interval between the arches filled with ruble-ſtone without mortar; but now the joints of the arch-ſtones are continued quite up to the cordon, and the looſe ſtones between the arches on the inſide are laid in the direction of the ſame joints: this way of finiſhing the courſes of the ſtones, both without and within, is certainly preferable to the former: but the beſt and only true method is, to form the outſide courſes, in the manner juſt now mentioned, and in the inſide, the arch-ſtones continued ſo as to form the curve, whoſe conſtruction has been given in the laſt problem of the ſecond ſection, part the firſt; this being done, and the ſtones ſo far laid in mortar, they will be in equilibrio with each other, as has been ſhewn in that ſection; the reſt may be filled up with looſe ſtones having proper bonds as uſual.

As the conſtruction of this exterior curve is ſo eaſy, its execution can admit of no difficulty; but becauſe we

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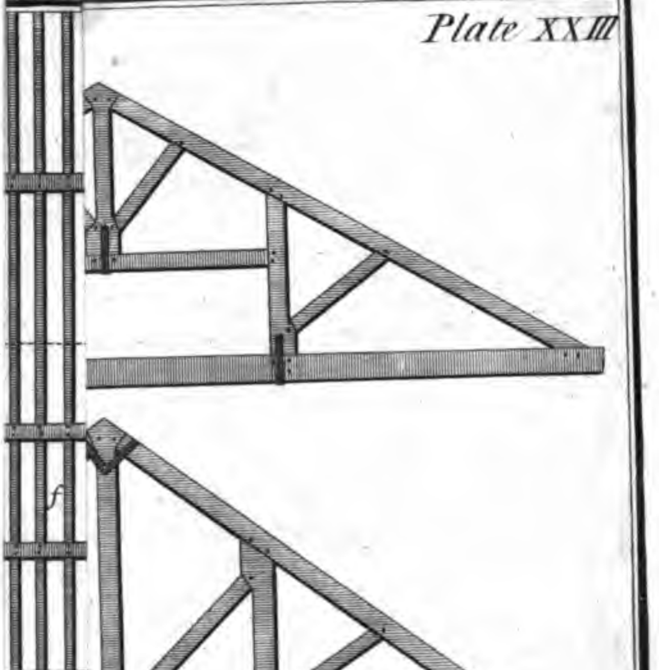
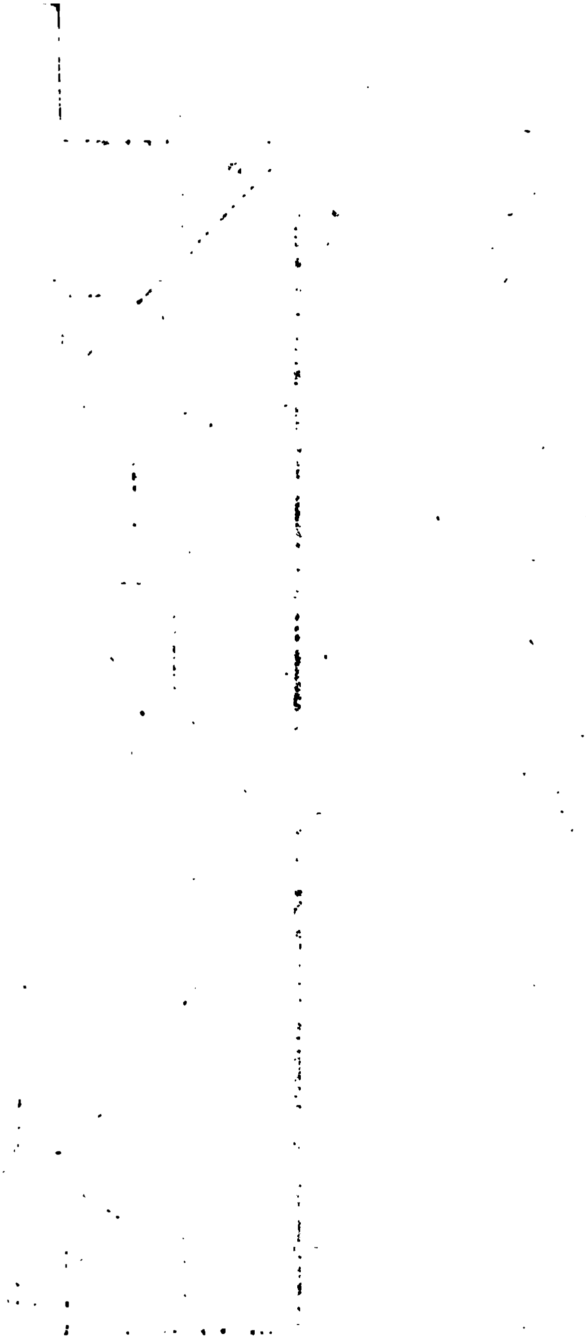
Plate XXIII



J. Couse Sculp.

UNI



we have not given that when the interior curve is an ellipſis, and we have proved that curve to be the beſt and only one to be uſed in bridges, we muſt beg leave to refer the reader to the fifth ſection of the third book of our mathematical treatiſe, where it is given; it was through overſight omitted in this work.

When the upper part of the bridge is finiſhed with ſtones in the manner mentioned above, ſo as to form one continued curvilinear ſurface, a bed of ſand and gravel is laid all over it, of about 6 feet deep, and then finiſhed with paving the middle paſſage, or with coarſe gravel, and the banquets are covered with flat ſtones for the foot paſſengers.

The ſpring of the arches ſhould begin at low-water mark, that is, that of the middle or greateſt, the reſt are raiſed ſomewhat higher, ſo as to make the upper part of the bridge of the propoſed deſcent, but in a ſituation where the ſwater wells very high in ſome particular ſeaſon of the year, regard muſt be had to that, and the arches muſt be raiſed accordingly.

The firſt figure of plate XXIV. is the elevation of a bridge with elliptic arches, the ſecond is the plan, and the third a ſection through the middle of the arch next to the abutment; the arches are 75 feet wide, the piers 12 high, and 15 broad; the angles at the extremities are right ones, and reach from the bed of the river quite up to the top of the parapet, where they form receſſes for paſſengers to retire into upon occaſion; but the foundation up to the bed of the river is rectangular, for reaſons mentioned hereafter. The ſection ſhews the wings of the bridge in front, and how the arch turns in that place.

We have thus given all the dimenſions of the ſeveral parts of ſtone bridges, (for the moſt part deduced from a well aſſerted theory, and therefore may be depended upon, with more ſecurity than thoſe given by other authors) and which are to be neceſſarily known before the building of a bridge is undertaken; we ſhall now ſhew how to proceed in the execution from the beginning of laying the foundation to the entirely finiſhing of the work.

How the work is to be carried on.

As the laying the foundation of the piers is the moſt difficult part of the whole work, it is neceſſary we ſhould begin with an eaſy caſe, that is, when the depth of the water does not exceed 6 or 8 feet; and then proceed to thoſe which may happen in a greater depth of water.

One of the abutments with the adjacent piers is incloſed by a dyke called ***batardeau*** by the ***French***, of a ſufficient width for the work, and room for the workmen; this batardeau is made by driving a double row of piles, whoſe diſtance is equal to the depth of water, and the piles in each row are 3 feet from each other; they are faſtened together on the outſide by bonds of 6 by 4 inches; this being done, frames of about 9 feet wide are placed on the inſide to receive the boards, which are to form the incloſure, the two uprights of theſe frames are two boards of an inch and half thick, ſharpened below to be driven into the ground, and faſtened together by double bonds, one below, and the other above, each ſeparated by the thickneſs of the uprights; theſe bonds ſerve to ſlide the boards between; after theſe frames have been driven into the ground as hard as can be, then the boards themſelves are likewiſe driven in till they reach the firm ground underneath,

Between every two piles tie-beams are faſtened to the bonds of the piles to faſten the inſide wall to the outſide one; theſe tie-beams are let into the bonds and bolted to the adjacent piles: This being done the bottom is cleared from the looſe ſand and gravel, by a machine like thoſe uſed by ballaſt-heavers; and then well prepared clay is rammed into this coffer very tight and firm, to prevent the water from oozing through.

Sometimes theſe incloſures are made with piles only driven cloſe to each other, at others the piles are notched or dove-tailed one into the other: but the moſt uſual method is to drive piles with grooves in them, 5 or 6 feet diſtant from each other, and boards are let down between them.

This being done, pumps and other engines are uſed to draw the water out of the incloſure, ſo as to be quite dry; then the foundation is dug, and the ſtones are laid in the ſame manner, and with the ſame precautions as have been mentioned in reſpect to thoſe of a fortreſs: obſerving to keep ſome of the engines always ſtanding, in order to draw out the water that may ooze through the batardeau.

The foundation being cleared, and every thing ready to begin the work; a courſe of ſtones is laid, the outſide all round with the largeſt ſtretchers and headers that can be had, and the inſide filled with aſhlers well jointed, the whole laid in terraſs mortar: the facings are crampt together, and ſet in lead; and ſome cramps are alſo uſed to faſten the facings with the inſide. The ſame manner is to be obſerved throughout all the courſes to the height of low-water mark; after which the facings alone are laid in terraſs mortar, and the inſide with the beſt of the common ſort.

The extent of the baſe of the foundation does not ſo much depend on the bigneſs of the piers as on the whole weight of the ſuperſtructure, which methinks has not always been ſo much conſidered as ſhould have been done; for it is ſaid, that every courſe ſhould project about a foot beyond that which is next above it from the height of low-water mark, whether the bridge be high or low, the arches circular or elliptic: but as every pier ſupports two half arches together with the weight of the ſtones laid between the hanches; the baſe ought to be regulated accordingly, as likewiſe in proportion to the height of the pier. When the foundation is carried to the height of low-water mark, or to the height where the arches begin, which ought to be either thereabout or at moſt two feet above it when the arches are elliptical; then the ſhaft or middle wall is to be carried up nearly to the height of the arches, and there left ſtanding till all the piers are finiſhed, in order that the maſonry may be ſufficiently dry and ſettled before the arches are begun.

As the piers end generally with an angle at each end, it is cuſtomary to lay the foundation in the ſame manner, which is not ſo well as to continue the baſe rectangular quite to the ends of the piers, and as high as low-water mark; both becauſe the foundation becomes then ſo much broader, and alſo becauſe the water will not be able to get under it: for when the current ſets againſt a flat ſurface, it drives the ſand and mud againſt it, ſo as to cover it entirely; whereas if a ſharp edge be preſented to the ſtream, it carries every thing away, and expoſes the foundation to the continual action of the water, which in courſe of time muſt deſtroy it.

The piers being all finiſhed, and the maſonry well ſettled; the next thing to be done is to frame and fix the centers, which ought to be ſo ſolid and ſtrong as to be able to ſupport the great weight of the arches; as their conſtruction is commonly known by workmen, and as thoſe made uſe of at *Weſtminſter-bridge* will be explained by Mr. *Labely* himſelf, we ſhall ſay no more of them than to obſerve, that they are fixed at the ends upon the projection of the foundation; and when the arches are very large they are ſupported in the middle by piles, and they muſt be raiſed by means of iron wedges about 3 inches higher than the arches are intended to be, in order to allow for the ſettling of the maſonry, theſe wedges by being looſened gradually ſerve to eaſe the center, ſo that it may only juſt touch the arch, and ſo facilitate the taking it quite away when the maſonry is ſufficiently ſettled.

The *French* engineers fix thin boards on each ſide with the directions of the joints marked upon them, for the conveniency of working with more ſpeed; this appears to be very uſeful, eſpecially when the arches are elliptical; they have patterns beſides for every joint, in order to cut the ſtones in a proper manner.

Theſe preparations being made, the ſtones of the firſt courſe are crampt together, as alſo all thoſe of every fifth courſe quite up to the key-ſtones. All the ſtones are to be laid in good ſtrong mortar, not very thick, ſo that they may lay as cloſe as poſſible, and cauſe but little ſettling: the arch being compleated, the center is eaſed by means of the wedges, but left ſtanding till the next arch is finiſhed; then it is taken away and made fit to ſerve for ſome other arch; ſo that there are not above three centers required to compleat the bridge.

After the intervals between the arches are filled up with ſtones laid in a regular manner without mortar, and the gravel is laid over them; two drains or gutters are made length-ways over the bridge one on each ſide next to the foot-path, of about 6 feet wide, and a foot deep; which being filled with ſmall pebble ſtones, ſerve to carry off the rain-water that falls on the bridge, and to prevent its filtering through the joints of the arches, as often happens.

If the ſame precautions were uſed here, as have been above recommended to prevent water from penetrating through arches conſtructed under ground, I ſhould imagine that this would be much better than the method commonly practiſed: for when the water paſſes through the joints of the arch-ſtones, as it does at *Weſtminſter* bridge, it has an ill effect to the eye, becauſe thoſe ſtones that are wet, look of a black colour different from the reſt.

How to build in water with COFFERS.

The former method of laying the foundation by means of batardeaus is very expenſive and often meets with great difficulties: for when the depth of water is 8 feet or more, it is ſcarcely poſſible to make the batardeaus ſo tight as to prevent the water from oozing through them, and in that caſe, the number of engines required, as well as the hands to work them, become very expenſive; and if part of the batardeau ſhould break by ſome extraordinary wind or tide, the workmen would be expoſed to very great danger.

Therefore the next and beſt method is to build with coffers, when it is practicable, ſuch as were uſed at *Weſtminſter bridge.* Since Mr. *Labely* promiſes to give a particular account of their conſtruction, and the manner in which they were uſed, we ſhall here mention ſome few things only, referring the reader for a fuller deſcription of them to this gentleman's work, a part of which has been publiſhed ſince the bridge was finiſhed.

The height of water was 6 feet at a medium when loweſt, and the tide roſe about 10 feet at a medium alſo; ſo that the greateſt depth of water was about 16 feet; at the place where one of the piers of the middle or great arch was to be, the workmen began to drive piles of about 13 or 14 inches ſquare, and 34 feet long, ſhod with iron, ſo as to enter into the gravel with more eaſe, and hooped above to prevent their ſplitting in driving them; theſe piles were driven as deep as could be done, which was 13 or 14 feet below the ſurface of the bed of the river, and 7 feet diſtant from each other, parallel to the ſhort ends of the pier, and at about 30 feet diſtant from them; the number of theſe piles was 34, and their intent to prevent any veſſels or barges from approaching the work, and in order to hinder boats from paſſing between them, booms were placed ſo as to riſe and fall with the water.

This being done, the ballaſt-men began to dig the foundation under the water, of about 6 feet deep, and 5 wider all round than the intended coffer was to be, with an eaſy ſlope to prevent the ground from falling in; in order to prevent the current from waſhing the ſand into the pit, ſhort grooved piles were driven before the two ends and part of the ſides, not above 4 feet higher than low-water mark, and about 15 feet diſtant from the coffer: between theſe piles, rows of boards were let into the groves down to the bed of the river and fixed there.

The bottom of the coffer was made of a ſtrong grate, conſiſting of two rows of large timbers, the one long-ways and the other croſs-ways, bolted together with wooden trunnels, ten feet wider than the intended foundation. The ſides of the coffer were made of fir timbers laid horizontally cloſe one over another pinned with oaken trunnels, and framed together at the corners, excepting at the two ſailant angles, where they were ſecured with proper irons, ſo that the one half might be looſened from the other if it ſhould be thought neceſſary; theſe ſides were lined on the inſide as well as on the outſide with three inch planks placed vertically; the thickneſs of thoſe ſides was 18 inches at the bottom, reduced to 15 above, and they were 16 feet high; beſides, knee-timbers were bolted at the angles, in order to ſecure them in the ſtrongeſt manner. The ſides were faſtened to the bottom by 28 pieces of timber on the outſide, and 18 within, called ſtraps, about 8 inches broad, and 3 or 4 inches thick, reaching and lapping over the ends of the ſides; the lower part of theſe ſtraps had one ſide cut dove-tail faſhion, in order to fit the mortiſes made near the edge of the bottom to receive them, and were kept in their places by iron wedges; which being drawn out when the ſides were to be taken away, gave liberty to clear the ſtraps from the mortiſes.

Before the coffer was launched, the foundation was examined, in order to know whether it was level; for which purpoſe ſeveral gauges were made, each of which conſiſted of a ſtone of about 15 inches ſquare, and 3 thick, with a wooden pole in the middle of about 18 feet long. The foundation being levelled and the coffer fixed directly over the place with cables faſtened to the adjacent piles; the maſons laid the firſt courſe of the ſtones for the foundation within it, which being finiſhed, a ſluice made in the ſide was opened near the time of low-water; on which the coffer ſunk to the bottom; and if it did not ſet level, the ſluice was ſhut, and the water pumpt out, ſo as to make it float till ſuch time as the foundation was levelled; then the maſons crampt the ſtones of the firſt courſe and laid a ſecond, which being likewiſe crampt, a third courſe was laid: then the ſluice being opened again, proper care was taken that the coffer ſhould ſettle in its due place. The ſtone-work being thus raiſed to within two feet of the common low-water mark, about two hours before low-water the ſluice was ſhut, and the water pumpt out ſo far as that the maſons could lay the next courſe of ſtone, which they continued to do till the water was riſen ſo high as to make it unſafe to proceed any farther; then they left off the work, and opened the ſluice to let in the water; thus they continued to work night and day at low-water, till they had carried their work ſome feet higher than the low-water mark; after this the ſides of the coffer were looſened from the bottom, which made them float, and then were carried aſhore to be fixed to another bottom, in order to ſerve for the next pier.

It muſt be obſerved, that the coffer being no higher than 16 feet, which is equal to the greateſt depth of water, and the foundation being 6 feet under the bed of the river; the coffer was therefore 6 feet under water when the tide was in; but being loaded with three courſes of ſtones, and well ſecured with ropes faſtened to the piles, it could not move from its place. By making it no higher much labour and expence were ſaved, yet it anſwered the intent full as well as if it had been high enough to reach above the higheſt flood.

The pier being thus carried on above low-water mark, the maſons finiſhed the reſt of it during the intervals of the tides in the uſual way; and after all the piers and abutments were finiſhed in a like manner, the arches were begun and compleated as mentioned before: the whole bridge was built in about ſeven years, without any accidents happening, either in the work or to the workmen, which is ſeldom the caſe in works of this nature.

It may be obſerved, that all the piers were built with ſolid *Portland* ſtone, ſome of them weighed four tons, the arch-ſtones were likewiſe of the ſame ſort, but the reſt of the maſonry was finiſhed with *Kentiſh rag-ſtones*; and the paths for foot paſſengers were paved with *Purbec*, which is the hardeſt ſtone to be had in this country, excepting *Plymouth* marble.

This method of building bridges is certainly the eaſieſt and cheapeſt that can be thought of, but cannot be uſed in many caſes: when the foundation is ſo bad as not to be depended upon without being piled, or the depth of water is very great, with a ſtrong current and no tide, I do not ſee how it can then be practiſed. For if piles are to be uſed, it will be next to impoſſible to cut them off in the ſame level five or ſix feet below the bed of the river, notwithſtanding that ſaws have been invented for that purpoſe; becauſe, if they are cut off ſeparately it will be a hard matter to do it ſo nicely that the one ſhall not exceed the other in height, and if this is not done, the grating or bottom of the coffer will not be equally ſupported, whereby the foundation becomes precarious: neither can they be cut off all together; for piles are to be driven as far as the bottom of the coffer extends, which at *Weſtminſter* bridge was 27 feet; the ſaw muſt have three feet play, which makes the total length filled a coffer containing 27 cubic feet, with maſonry made of this mortar, and ſunk it into the ſea, it was there left ſtanding for two months, and when it was taken out again, it was harder than ſtone itſelf. Where ſuch mortar can be made, this method has certainly the advantage over all the others, not only in building the piers of bridges over deep rivers, but likewiſe in making piers for harbours, and in all other aquatic works; but before it is made uſe of, I would adviſe the engineer to make firſt a trial of his mortar; ſince works of this nature are of too great conſequence to be carried on without an abſolute certainty of ſucceſs.

We have hitherto mentioned ſuch ſituations only where the ground is of a ſoft nature; but where it is rocky and uneven all the former methods prove ineffectual; nor indeed has there yet been any one propoſed that I know of, which might be uſed upon ſuch an occaſion, eſpecially in a great depth of water; but as an engineer ought to know how to proceed upon all occaſions, we ſhall therefore mention ſome few obſervations under this head. When the water is not ſo deep but that the unevenneſs of the rock can be perceived by the eye, piles ſtrongly ſhod with iron, may be raiſed and let fall down by means of a machine, upon the higher parts, ſo as to break them off piece by piece, till the foundation is tolerably even, eſpecially when the rock is not very hard; which being done either this or any other way that can be thought of, a coffer is made without any bottom, which is let down and well ſecured, ſo as not to move from its place; to make it ſink, heavy ſtones ſhould be fixed on the outſide; then ſtrong mortar and ſtones muſt be thrown into it; and if the foundation is once brought to a level, large hewn ſtones may be let down ſo as to lie flat and even; by theſe means the work may be carried on quite up to the ſurface of the water.

But when the water is ſo deep, or the rock ſo hard as not to be levelled, the foundation muſt be founded, ſo as to get nearly the riſings and fallings; then the lower part of the coffer muſt be cut nearly in the ſame manner, and the reſt finiſhed as before. It muſt however be obſerved, that we ſuppoſe a poſſibility of ſinking a coffer, but where this cannot be done, no method that I know of will anſwer; and therefore I leave it to the judgment and knowledge of the engineer employed upon ſuch an occaſion, in what manner he is to proceed.

Among the aquatic buildings of the ancients none appear to have been more magnificent than *Trajan's* bridge. *Dion Caſſius* gives the following account of it: "*Trajan* built a bridge over the *Danube*, which in "truth one cannot ſufficiently admire; for though all "the works of *Trajan* are very magnificent, yet this "far exceeds all the others: The piers were 20 in "number, of ſquare ſtone; each of them 150 feet high "above the foundation, 60 feet in breadth, and diſtant "from one another 170 feet. Though the expence of "this work muſt have been exceeding great, yet it becomes "more extraordinary by the river's being very "rapid, and its bottom of a ſoft nature: where the "bridge was built, was the narroweſt part of the river "thereabout, for in moſt others it is double or treble "this breadth; and although on this account it became "ſo much the deeper and the more rapid, yet no other "place was ſo ſuitable for this undertaking. The arches "were afterwards broken down by *Adrian*; but the piers "are ſtill remaining, which ſeem as it were to teſtify, "that there is nothing which human ingenuity is not "able to effect." The whole length then of this bridge was 1590 yards; ſome authors add, that it was built in one ſummer, and that *Apollodorus* of *Damaſcus* was the architect, who left behind him a deſcription of this great work. It is a great loſs to the world that his deſcription has not come down to us, ſince it would have ſhewn both how theſe works were carried on for-

merly

merly and how far modern builders are inferior to the antients.

SECT. II.

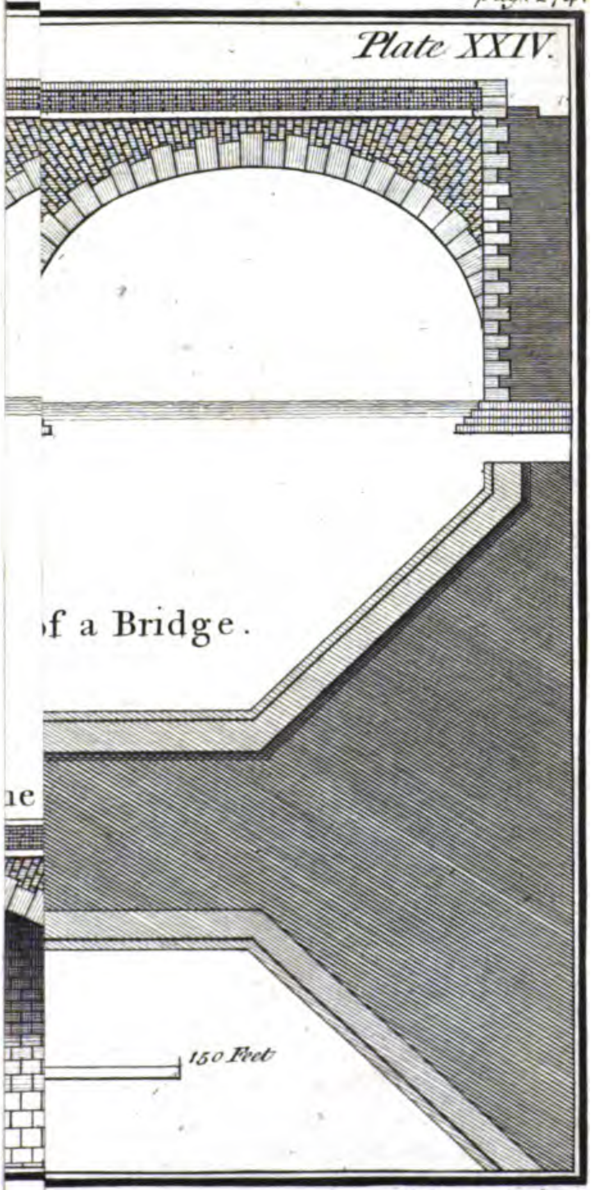
Of HARBOURS.

THE making and incloſing harbours with piers, ſo as to reſiſt the wind and waves for the preſervation of ſhips in ſtormy weather, is one of the moſt uſeful and neceſſary works that can be made in a trading nation, ſince the ſecurity of their wealth and power depends greatly upon it; for many ſhips have been caſt away, and the lives of many people loſt, for want of a ſecure harbour, which might have been ſaved for a moderate ſum of money, had it been properly applied.

Though engineers are not generally employed here in *England* in ſuch kind of works, yet it is properly their buſineſs; this may perhaps rather be owing to their want of ſkill in them than to any thing elſe: but ſince fortreſſes are generally built near the ſea or navigable rivers for the ſecurity of trade, and this cannot be ſecured without building ſafe harbours; therefore it ought to be the particular ſtudy of every young engineer, who is deſirous of being uſeful to his country, or of diſtinguiſhing himſelf, to make himſelf maſter of this branch of buſineſs.

As it ſeldom happens that ſuch works are carried on at home, he ſhould attentively examine thoſe harbours already executed, both at home and abroad, and take notice of their figure, ſituation, entrance, wind and tide, whether the ſhips can go in with ſafety in foul weather, and out when favourable; whether it would have been better if the entrance had been made elſewhere; whether the piers are ſtrong and ſolid, or want often to be repaired, and in general whether the harbour

Plate XXIV.



J. Couse Sculp.

UNIV. OF MICH.

harbour anſwers in every reſpect the intention for which it was built.

He ought to get information from the inhabitants, workmen, or the builder himſelf, if he is alive; to know the reaſons for making it of that figure, why the entrance is placed in that ſituation, how the foundations were laid, what accidents happened, how long it was in building, what number of hands were employed, and what the expences have been.

Having thus examined as many harbours as he could conveniently ſee, and having made himſelf acquainted with the manner of their building, he will be able to judge, when a new one is propoſed, whether the ſituation is proper or not, and how it may be executed in the beſt and ſecureſt manner, together with what the expences would nearly come to.

But before a young engineer enters upon practice, he ſhould have a proper knowledge of the mathematics, eſpecially of that part which treats of the mechanical powers and hydraulics, in order to know in what manner engines are conſtructed and applied to the ſeveral uſes they are intended for; this he may obtain by conſulting thoſe authors who have written upon them, and by examining the engines themſelves, to ſee if they anſwer the intention, or whether they might not be improved; or elſe, if others could not be invented of a different form, which would be more ſimple, and more expeditious.

In order to aſſiſt beginners, we ſhall ſet down here the principal enquiries to be made before a harbour is executed, the manner of laying the foundation, and how the works are to be carried on moſt ſecurely, in the plaineſt and eaſieſt manner that we could think of, and which has been approved of by moſt authors who have treated of this ſubject.

The firſt thing to be conſidered is the ſituation, which may be ſome large creek or baſon of water, in or near the place were the harbour is intended to be made, or at the entrance of a large river, or near the ſea; for a harbour ſhould never be dug entirely out of dry land, unleſs upon ſome extraordinary occaſions, where it is impoſſible to do otherwiſe, and yet a harbour is abſolutely neceſſary; when a proper place is found, before it is fixed upon, it muſt be conſidered whether ſhips can lie there ſafe in ſtormy weather, eſpecially when thoſe winds blow which are moſt dangerous upon that coaſt; whether there be any hills, riſing ground, or high buildings that will cover it; in theſe caſes the ſituation is very proper; but if there be nothing already that will cover the ſhips, it muſt be obſerved whether any covering can be made at a moderate expence, otherwiſe it would be uſeleſs to build a harbour there.

The next thing to be conſidered is, whether there be a ſufficient depth of water for large ſhips to enter with ſafety, and lie there without touching the ground, and if not, whether the entrance and inſide might not be made deeper at a moderate expence; or in caſe a ſufficient depth of water is not to be had for large ſhips, whether the harbour would not be uſeful for ſmall merchantmen; for ſuch a one is often of great advantage when ſituated upon a coaſt much frequented by ſmall coaſting veſſels.

The place where the entrance is to be made ought to be well conſidered; it ought to be ſuch that the ſhips may enter in foul weather and go out when fair: for though ſhips may enter when in diſtreſs, yet if they cannot go out when the wind is fair to purſue their voyage and not to loſe their market; ſuch a harbour would not anſwer the end for which it was deſigned.

It is therefore neceſſary to conſider well the current, tide, and winds, as alſo the banks of ſand near about it; and to conſult the maſters of ſhips as well as the pilots who live thereabout, or frequent the coaſt: they are better judges where the entrance ſhould be than any body elſe; but if it ſhould happen that they are divided in their opinions, as it often is the caſe; it will be prudent not to determine the ſituation of the entrance till part of the piers are built, and ſufficient obſervations made, where it will be moſt convenient.

When a ſituation has been found that has all or moſt of theſe requiſite advantages, an enquiry is to be made concerning the materials to be uſed in building the piers, where they are to be had, if upon the ſpot, near at hand, or when at a diſtance, whether they are to be brought by land or water carriage, or partly one way and partly the other; their prime coſt muſt be known, the expence for bringing them to the ſpot, the time required, and the expence of the workmanſhip to make them ready for uſe.

All theſe preparative enquiries being made, the form or figure of the harbour muſt be determined in ſuch a manner that the ſhips which come in when it is ſtormy weather may lay ſafe, and ſo as there may be ſufficient room for as many as paſs that way: the depths of water where the piers are to be built, muſt be taken at every ten, fifteen, or twenty feet diſtance, and marked upon piles driven here and there, in order that the workmen may be directed in laying the foundation.

This being done, it muſt be conſidered what kind of materials are to be uſed, whether ſtone, brick, or wood; when ſtones are to be had at any moderate price, they ought to be preferred, becauſe the work will be much ſtronger, more laſting, and need fewer repairs than if made with any other materials: but when ſtones are ſcarce, and the expence becomes greater than what is allowed for building the harbour, the foundation may be made of ſtone as high as low-water mark, and the reſt finiſhed with brick. If this manner of building ſhould ſtill be too expenſive, wood muſt be uſed; that is, piles are driven as cloſe as is thought neceſſary, which being faſtened together by croſs-bars, and covered with ſtrong oaken planks, form a kind of coffer, which is filled with all kinds of ſtones, chalk, and ſhingles, as will be explained more at large hereafter.

The materials being fixed upon, an eſtimate is made of the expences; the number of hands to be employed at a time is determined, ſo as they may conveniently work without interfering with one another; and from thence it may be nearly computed what time will be required for compleating the whole work.

The manner of laying the foundation in different depths of water, and in various ſoils, requires particular methods to be followed: when the water is very deep, the *French* throw in a great quantity of ſtones at random, ſo as to form a much larger baſe than would be required upon dry land; this they continue to within 3 or 4 feet of the ſurface of the water, where they lay the ſtones in a regular manner, till the foundation is raiſed above the water; they then lay a great weight of ſtones upon it, and let it ſtand during the winter to ſettle, as likewiſe to ſee whether it is firm, and reſiſts the force of the waves and winds; after that they finiſh the ſuper-ſtructure with large ſtones in the uſual manner.

As this method requires a great quantity of ſtones, it can pe practiſed but in few places where ſtones are in plenty; and therefore the following one is much preferable. A coffer is made with dove-tail piles of about 30 yards long, and as wide as the thickneſs of the foundation is to be; then the ground is dug and levelled in the manner deſcribed in the laſt ſection; and the wall is built with Beton mortar, as has been deſcribed in the ſame ſection.

As ſoon as the mortar is tolerably dry, thoſe piles at the end of the wall are drawn out, the ſide rows are continued to about 30 yards farther, and the end incloſed, then the foundation is cleared, and the ſtones laid as before. But it muſt be obſerved, that the end of the foundation finiſhed is left rough, in order that the part next to it may incorporate with it in a proper manner; but if it is not very dry it will incline that way of itſelf, and bind with the mortar that is thrown in next to it; this method is continued till the whole pier is entirely finiſhed.

It muſt likewiſe be obſerved, that the piers are not made of one continued ſolid wall; becauſe in deep water it would be too expenſive; for which reaſon, two walls are built parallel to each other, and the interval between them is filled up with ſhingle, chalk, and ſtone: As theſe walls are in danger of being thruſt out or overſet, by the corps in the middle, together with the great weight laid at times on the pier, they are tied or bound together by croſs-walls at every 30 or 40 yards diſtance, by which they will ſupport each other in a firm and ſtrong manner. For want of theſe croſs-walls it has happened not many years ago, that the walls of a work were overſet for the ſpace of ſome hundred yards.

If ſuch mortar can be made as what the *French* call Beton, there can ſcarcely be found a better method than that above for laying foundations in deep water, and it may be uſed upon all occaſions; but as ſuch mortar is not every where to be had without great expences; I imagine that common terraſs mortar, mixt with ſmall ſtones and ſome cinders, if to be had, will anſwer the purpoſe as well; but the engineer, who is to carry on the work, ought to make trial of it before he uſes it.

If the foundation be bad to a great depth, I would ſink it only about 4 feet below the bed of the river; and lay a ſtrong grate of timber, as in thoſe of the piers of a bridge; but if it ſhould be rocky, a coffer muſt be made without a bottom, and the under part cut nearly with the ſame riſings and fallings, according to the manner mentioned in the laſt ſection.

In a country where there is a great plenty of ſtones, piles may be driven in as deep as they will go, at about two or three feet diſtance, and when the foundation is ſunk and levelled, large ſtones may be let down, which will bed themſelves; but care muſt be taken to lay them cloſe, and ſo as to have no two joints over each other; and when the wall is come within reach, the ſtones muſt be crampt together.

Another method practiſed, is to build in coffers much after the ſame manner as has been done in building the piers of *Weſtminſter-bridge*; but as in this caſe the ends of the coffers are left in the wall, and prevent their joining ſo well as to be water-tight, the water that penetrates through and enters into the corps, may occaſion the wall to burſt and to tumble down. Another inconveniency ariſing from this manner of building is, that as there are but few places without worms, which will deſtroy wood wherever they can find it; by their means the water is let into the pier, and conſequently makes the work liable to the ſame accident as has been mentioned above.

To prevent the inconveniencies of this method, I would take the wood away, and joggle the ends of the walls together with large ſtones, and pour terraſs mortar into the joints; when this is done, the water between the two walls may be pumpt out, and the void ſpace filled up with ſtone and ſhingle as uſual: or if theſe joggles cannot be made water-tight; ſome dove-tail piles muſt be driven at each end as cloſe to the wall as can be done, and a ſtrong ſail-cloth put on the outſide of them, which, when the water is pumpt out, will ſtick ſo cloſe to the piles and wall, that no water can come in. This method is commonly uſed in *Ruſſia*, as I have been informed.

Plate XXV. In order to underſtand clearly the method of building piers, we have given the plan and ſection of one of the walls, in the firſt figure, ſuch as had been propoſed for incloſing a harbour, upon a chalky foundation; the water is but 6 feet high when loweſt, and riſes to 24 when the tide is in. The manner propoſed for building the piers, was to dig the foundation about two feet deep, which is ſufficient for ſuch a ground,

a ground, and to ſink large blocks of ſtone of about 3 feet high, which could have eaſily been crampt together at 3 or 4 feet under water; then to lay another courſe of large ſtones over the firſt, and to cramp them as before; the ſame thing was to be done, till the wall was carried about two feet above low-water mark: or if this method of laying the foundation was not approved of, to lay it in coffers in the manner mentioned above.

It was ſaid, that the funds allowed for building the harbour were not ſufficient to make the piers entirely of ſtone; for which reaſon, the reſt was to have been continued with hard bricks, ſuch as are called clinkers, to about 8 feet high, then a courſe of ſtones was to be laid of a foot high and crampt together; after this bricks were to be laid again to the ſame height as before, and then another courſe of ſtone, this was to have been continued quite up to the entire completion of the pier.

The ſtone foundation being 8 feet high, that is, from two feet under the bed of the water to low-water mark; and from thence to the top being 23 feet; therefore the inſide wall is five feet higher than high-water mark; and as the outſide wall has a parapet of 5 feet high, and 3 or 4 thick; this wall is ten feet higher than the water when the tide is in; which height was thought neceſſary, in order to cover the people ſtanding there, from the water, becauſe the waves riſe very high in that place, at certain times of the year.

The walls were to be 28 feet diſtant from each other, five feet thick above, and the baſe of the ſlope one fifth of the height; which would have made the thickneſs of the piers 34 feet above, beſides the parapet, which takes up 4, and 50 near the bottom of the water. At every 30 feet diſtance was to be made a croſs or tie-wall, of three feet thick, to bind the two walls together; this diſtance may be greater near the ſhore, where the waves have not ſo great a force as farther from it; and to let them be ever ſo great: it is true, that moſt of the workmen will think it inſufficient, as having no braces, of which they are ſo fond, that they think no work well ſecured without them; but as I do not eſteem them neceſſary, I have omitted them here.

In thoſe wooden piers I have ſeen, there was no baſe made with ſhort piles, ſuch as are repreſented in the ſecond figure; for the long piles reached from top to the bottom, and no dovetail piles were driven to ſecure the foundation, as far as I could find; but ſince ſuch works ought to be made in the moſt ſecure manner, and ſo as not to want continual repairing; I would adviſe the directors of them, to conſider well the nature of the ſituation, as well as the importance of the harbour, before they form a ſcheme for building the piers.

What has been ſaid here in regard to the building of piers for harbours will equally ſerve for that of quays, and all other works made in water; it muſt only be obſerved, that as quays are often loaded with very great weights, the wall muſt be made much ſtronger than thoſe of ramparts, which ſupport the preſſure of earth only. But to give ſome rule whereby the reader may be directed, I imagine that, if the thickneſs be treble that of the wall of a rampart of the ſame height, it will be ſufficient: thus if the height of the quay be 10 feet, and the baſe of the ſlope one ſixth of the height; by trebling the height 1.5 feet, found in table the firſt, for the thickneſs above of a wall of the ſame height, we get 4.5 feet for the thickneſs above of the ſaid wall. To ſecure theſe walls yet better, piles are driven on the inſide about 20 feet diſtant from the wall, and about 15 feet from each other; the heads of which are tenoned into a beam, and others being laid acroſs are let into this beam at one end, and at the other going through the wall are fixed to the fenders on the outſide with iron ſtraps bolted into theſe beams.

SECT.

Plate XXV.

of a wooden Pier.

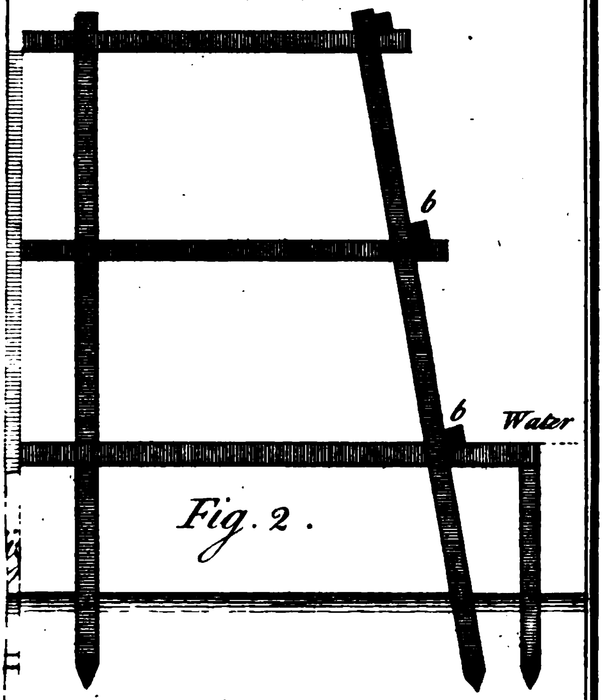
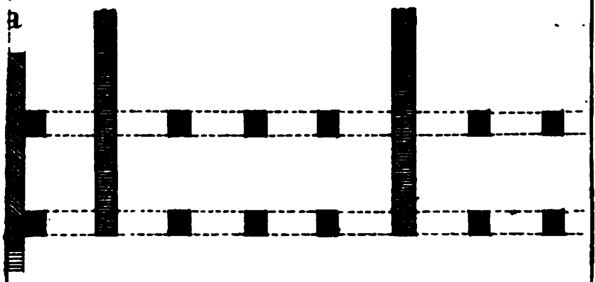


Fig. 2.

wooden Pier.



J. Couse Sculp.

UNIV. OF M

SECT. III.

Of SLUICES *and* AQUEDUCTS.

SLUICES are made for various purpoſes; ſuch as to make rivers navigable; to join one river to another, which is higher or lower, by means of a canal; to raiſe inundations upon particular occaſions, or to drain ſpots of ground that are overflown by high tides: they are alſo made in fortreſſes, to keep up the water in one part of the ditches whilſt the other is dry; and to raiſe an inundation about the place when there is any apprehenſion of being attacked.

Sluices are made different ways, according to the uſes they are intended for; when they ſerve for navigation, they are ſhut with two gates preſenting an angle towards the ſtream; when they are made near the ſea two pair of gates are made, the one to keep the water out and the other in, according as occaſion requires; in this caſe, the gates towards the ſea preſent an angle that way, and the others the contrary way; the ſpace incloſed by theſe gates is called *chamber*.

When ſluices are made in the ditches of a fortreſs to keep up the water in ſome parts, inſtead of gates, ſhutters are made, ſo as to ſlide up and down in grooves; and when they are made to raiſe an inundation; they are then ſhut by means of ſquare timbers let down into *culliſes*, ſo as to lie cloſe and firm.

Particular care muſt be taken in the building of a ſluice, to lay the foundation in the ſecureſt manner that is poſſible; to lay the timber grates and floors in ſuch a manner that the water cannot penetrate through any part, otherwiſe it will undermine the work, and blow it up, as it has ſometimes happened: Laſtly, to make the gates of a proper ſtrength, in order to ſupport the preſſure of the water, and yet to uſe no more timber than what is neceſſary.

As a general conſtruction is much preferable to particular ones, we ſhall follow the example of Mr. *Belidor*, who is the firſt that gave one for ſluices; but before this can be done, it is neceſſary to know its width, and the depth of water it is to contain, and from thence the dimenſions of the ſeveral parts are determined, as will be ſhewn hereafter.

When ſluices are made in a canal, or navigable river, their width will be known from the ſize of the veſſels that are to paſs through them, as well as the depth of water they require; when they are made in a fortreſs to pen up the water in one part, and to keep the other dry, their width is determined by the quantity of water that is to paſs through them in a certain time: When they are near the ſea, or a river where there is a tide, and they are to keep up the water at a certain height; their width and depth are alſo determined from the nature of the ſituation; and in general, the width and depth of a ſluice is always known from its ſituation, and the uſe it is intended for.

This being premiſed, we ſhall give a general conſtruction of a great ſluice with two pair of gates, in ſuch a manner as to be applicable to any particular caſe, provided a proper allowance be made for the various circumſtances that may happen, in regard to their uſe and ſituations, which may change ſome of the parts, as ſhall be mentioned in its proper place.

To conſtruct the PLAN *of a* SLUICE.

Plate XXVI. Suppoſe half the width OC to be divided into ſix equal parts, or the whole into twelve; theſe parts ſerve for a ſcale, whereby the dimenſions of the work are determined: through the point O, draw the line AB at right angles to OC; take OB on one ſide of the point O equal to 30 of theſe parts, or which is the ſame, equal to two widths and a quarter; through

the points A, B, draw the lines AR, AS at right angles to AB; let the lines paſſing through the point C, and parallel to AB, meet theſe laſt lines in M, Q; then if MN, PQ be taken each equal to 9 parts, and each of the lines MR, QS equal to 6, the lines NR and PS will determine the wings of the ſluice, and NP the body. If the lines AR, BS be produced ſo as the parts RV, ST are each 6; they will determine the faces.

The part AB of the length exceeds the other part OA by one fourth of the width, becauſe we ſuppoſe a turning bridge is to be placed on that ſide for a communication from one ſide of the ſluice to the other; but when there is no occaſion for ſuch a bridge, OB is made no longer than OA; and then the total length will be but four times and a half the width, which is eſteemed by Mr. *Belidor* the beſt length that can be given to a great ſluice.

To determine the chamber and the poſition of the gates, take OD, OL, each equal to four parts, and draw the lines DG, LH parallel to OC; then if the lines GK, HI be drawn ſo as to make the angles DGK, LHI, each of 35 degrees, and 16 minutes, that poſition will be the beſt that can be given, by art. 566 of our *Elements of Mathematics*, or becauſe a linear conſtruction is preferable to that by angles; the poſition of the lines GK, HI, is determined in the ſame manner as the line AE in fig. 7, plate the fifth, page 90, of this work.

The cavities *z*, *y*, are a foot each way in large ſluices, and but 9 inches in middling ones; they ſerve for letting down ſquare timbers to form a batardeau on each ſide, in caſe the gates or floor want to be repaired.

The receſſes G*a*, H*b* in the wall, are made to receive the gates when open, and are of ſuch a depth that they may be fluſh with the wall, and not make that part narrower than the reſt of the ſluice.

The thickneſs of the wall from N to P is equal to four fifths of the depth of water, the parts R N, P S, three fifths, and at V, T two fifths. The counterfort W, is determined by producing the lines L H, D G, and projects beyond the wall by one fourth of the width of the ſluice.

OBSERVATIONS *on this* CONSTRUCTION.

As we differ in ſome parts of our conſtruction from that given by Mr. *Belidor*, it will not be improper to acquaint the reader with the reaſons that have induced us to do ſo. *Firſt*, We made the length L D, equal to 8 parts inſtead of 7, to avoid a ſubdiviſion of parts; the difference of one part being immaterial. 2. According to our conſtruction, the length G K of the gates comes out to be 7.34 parts nearly; and as Mr. *Belidor* makes the lines D K one fifth of the width, the length of his gates is 6.46 parts nearly; but as our conſtruction gives the moſt advantageous poſition, and that of Mr. *Belidor's* depends on no ſubſtantial reaſons, we imagine that the diſpoſition here given is preferable to his: It is true, he has endeavoured to prove that his poſition is that which the gates ought to have, but all his reaſoning is grounded upon wrong ſuppoſitions; beſides as the length of our gates does not differ above 38 inches in the largeſt ſluice that is made, from the length he gives, we imagine that this difference is more than recompenced by the true poſition. 3. Mr. *Belidor* makes the lines M R, Q S, 7 parts inſtead of 6, which difference is very little.

As to the thickneſs of the ſide-walls, Mr. *Belidor* makes it equal to the depth of water in the ſluice, in order, as he ſays, that they may be ſo ſtrong as to reſiſt in all accidents that can happen; beſides, he adds five counterforts on each ſide, their length is equal to the thickneſs of the wall, and the mean thickneſs five eighths of their length.

It is certain, that in conſtructing ſuch works as theſe, particular care ſhould be taken to make them ſtrong and durable, yet it ought to be conſidered, that by making uſe of more maſonry than is neceſſary, it encreaſes the expences conſiderably, and therefore all exceſſes ſhould be avoided.

Now the proper thickneſs of theſe walls may be determined in the ſame manner as that of thoſe which ſupport earth, by comparing the ſpecific gravity of water to that of ſtone or brick; but it muſt be obſerved, that the triangular ſection of water has its baſe at the bottom inſtead of being above, as in the ſection of earth: by this method it will be found, that if the thickneſs of a ſtone wall be four fifths of the depth of the water, as we have made it, it will be able to ſupport a preſſure four times greater than that of the water; which in my opinion is ſufficient upon all occaſions whatſoever: but when the wall is made of brick, its thickneſs muſt be equal to the depth of water, in order to have the ſame ſtrength.

Hence it will be found, that the quantity of maſonry contained in a ſluice, according to our conſtruction, is to the quantity according to Mr. *Belidor's*, as 542 to 723, or as 3 to 4 nearly; therefore, if one fourth of the maſonry can be ſaved, as it appears by what has been ſaid, without making the walls too weak, the method we propoſe has greatly the advantage of that given by Mr. *Belidor*.

It may be obſerved, that the walls have been ſuppoſed to have no ſlope, but in practice they have, or ought to have one on the outſide, and as there is likewiſe the preſſure of the earth, which helps to ſupport the wall; by theſe means its reſiſtance is ſtill greater than we have ſuppoſed it to be.

It muſt alſo be obſerved, that as the width of the ſluice is divided into as many parts as there are inches in a foot; each part will be as many inches as the width is feet; ſo that when the width of a ſluice is given in feet, the value of each part is known; thus if the ſluice is to be 42 feet wide, each part will be 42 inches, or 3 feet 6 inches, and ſo in any other caſe.

When a ſluice is built in a place where a great quantity of water is to paſs, two or more paſſages are to be made; that is, two or more ſluices are built at the ſide of each other; theſe paſſages have ſometimes the ſame width, and at others not, according to the circumſtances that render them more uſeful one way than another.

Whence in a ſluice that ſerves to form an inundation, or to keep up water, theſe paſſages are made of an equal width; but in canals and large rivers that ſerve for navigation, the one is made ſo wide as that large veſſels may go through it, and the other ſerves for ſmaller veſſels. This has been done in the canal at *Mardick*, where the largeſt is 44 feet, and of conſequence wide enough for the ſecond rate of men of war to paſs through it, and the other is 24 feet, which ſerves for ſmaller veſſels.

Of the TIMBER-GRATES *under the* FLOOR *and* FOUNDATION.

If the foundation be bad, we ſuppoſe piles to be driven under the croſſings of the ſleepers *m*, and the tie-beams *n*, in the manner mentioned in the ſeventh ſection of the third part; and to prevent the water from getting under the foundation, ſix rows of dove-tail piles are driven, *viz.* one at each end, one at each of the angles N, P, marked *p*, and one on each ſide of the chamber; and it muſt be obſerved, that excepting thoſe at the angles N, P, the reſt are all driven between two ſleepers, in order to keep them tight and cloſe together. The ſleepers and tie-beams are partly let into each other, and bolted together; but before this is done, the looſe earth is removed from between the ſleepers for about two or three feet deep, and filled up with maſonry

ſonry before the tie-beams are laid: this maſonry is carried on ſo, as that when a bed of mortar is laid over it, it may be even with the upper ſurface of the ſleepers; then the inſide of the ſluice is covered with a floor of three inch thick oaken planks, laid long-ways, and nailed to the ſleepers; this floor extends a few inches on each ſide over the foundation of the ſide-walls, to prevent the water from penetrating through the edges of the floor.

Bricks are uſed preferably to ſmall ſtones, to fill up the parts between the grating, as lying much cloſer, and filling up every part exactly; they are laid in terraſs mortar as well as the reſt of the foundation. This being done, the frames made to ſupport the gates at the bottom, are laid in their proper places, which are compoſed of a ſell *r*, two hurters *s*, two braces *v*, and a tong *t*. The ſell enters about three feet into the ſide-walls, and the ſockets to receive the pivots of the gates are placed in it; the tong ought to be ſo long as to croſs three ſleepers, to which it is faſtened in a ſtrong manner. The ſell, tong, and the hurters, ought to have the ſame dimenſions, and their height muſt be ſuch as to be a foot above the laſt floor of the ſluice, as well as the floor of the chamber; for which reaſon, the piles under the chamber are left a foot higher than the reſt.

After this another row of ſleepers is laid exactly over the firſt, and a row of tie-beams, ſo as to anſwer likewiſe thoſe underneath; which being let into one another, and bolted together as before, and the vacancies between them being filled up with maſonry, and a bed of mortar laid over it, ſo as to be even with the upper ſurface of the ſleepers; then a ſecond floor is laid, of the ſame dimenſions and extent with the former; and when this is done, the ſide walls are built in the manner which will be mentioned preſently.

Upon the ſecond floor is laid another of two inch thick planks only, which does not enter the wall, in order that it may be repaired when it is wanted. This laſt floor may be made of yellow deal, and its ſeams muſt be well caulked to prevent the water from penetrating through them.

The walls muſt be made about three feet higher than the greateſt depth of water, to prevent the waves from paſſing over them; the facings are made with the largeſt ſtretchers and headers that can be had, laid in terraſs mortar, and crampt together; the reſt of the work is done with good common mortar.

The foundation muſt be made larger than the wall, and in proportion to the weight it is to ſupport, and the top muſt be covered with large flat ſtones or bricks ſet long-ways laid in terraſs mortar, to prevent the water from penetrating into the maſonry, which otherwiſe would deſtroy it in a ſhort time.

When the wall is finiſhed, a bed of clay is rammed againſt it of two feet thick all round the outſide, beginning as low as the foundation, and raiſed as high as the wall.

To prevent the water from carrying off the earth by its fall, at the ends of the ſluice a falſe floor of faſcines is made of as many fathoms long as the water in the ſluice is feet high; this bed or falſe floor is ſunk into the ground as far as is found neceſſary; but firſt of all a bed of clay is laid, and well rammed, then beds of faſcines are laid long-ways, and faſtened with pickets; when the faſcines are nearly level with the floor of the ſluice, pickets are driven acroſs in rows three feet diſtant from each other, reaching a little above the faſcines, and about each row two branches or poles are twiſted of about an inch diameter, ſo as to croſs each other between the pickets, which being beat down with a mallet, will keep the faſcines very cloſe and tight together; the cavities between theſe rows of pickets and branches are filled up with a pavement of hard ſtones a foot long, ſet long-ways, well beat down, ſo as the current may not tear them open.

For a greater ſecurity, a row of dove-tail piles is driven at each end; and it may be obſerved, that both floors muſt have a gradual deſcent from the chamber of about a 48th part of the length, in order that the water may run off clear, when the ſluice is laid dry, and any repairs are wanted to be made.

Aqueducts are ſometimes made in the ſide-walls going round the chamber, and coming out before the gates, in order that the water may paſs upon occaſion from one ſide of the ſluice to the other, without being obliged to open the gates; they have a ſhutter near each end, that ſlides in grooves, which are drawn up, or let down, when there is occaſion for it. But as wickets are commonly made in the gates, which may ſerve for the ſame purpoſe, unleſs on ſome occaſion where the chamber is required to be left dry, and yet it is abſolutely neceſſary that the water ſhould paſs from one ſide to the other; we have therefore not marked them in the plan, but they may eaſily be made whenever it is thought proper.

The croſs-ſection ſhews the poſition of a row of piles, and the ſleepers above them into which they are tenoned; the ſections of the tie-beams; the floor between them; the ſell, and the two floors above it; there is alſo ſeen a row of dove-tail piles, broken off in the middle, in order to ſee part of the maſonry *a*, *a*, beween the piles and under the ſleepers. The outſide of the gates are likewiſe ſeen in this ſection; how the planks are joined to the frame; the ſhutters *x*, *x*, and the irons both of the gate and ſhutters. In the conſtruction of gates, particular care ſhould be taken, to join the ſeveral pieces together in ſuch a manner, that the whole frame may be as ſtrong as poſſible, and not to make them heavier than needs muſt be, to prevent their ſinking, which is not eaſily done in large ſluices; nor yet too weak, for fear of their not being able to ſuſtain the great preſſure which is againſt them.

The

The principal frame of a gate conſiſts of two ſtiles or uprights; that which is next to the wall and to which the pivots are fixed, is called the pivot-poſt, and the other the chamfered ſtile, from being edged off on the inſide, ſo as to make a plain joint with the other gate: theſe two ſtiles are joined by two rails which are tenoned into them. The other pieces, which are not ſeen in this ſection, but ſerve to ſtrengthen the gate, conſiſts of ſeveral rails placed not nearer to each other than inches, nor farther than 30; and of ſeveral braces which 24 form the ſame angle with the pivot-poſt as the joints of the planks on the outſide, and they are tenoned into the rails; laſtly, of two monions or ſhort uprights to form the wickets.

As it is too nice a calculation to find the proper ſtrength of each piece in ſuch a manner as may be depended upon in practice, we ſhall give their dimenſions, ſuch as are inſerted in Mr. *Belidor's* works, and which, he ſays, have been taken from thoſe moſt approved of in practice.

The pieces of the principal frame are generally made of the ſame dimenſions, though ſome will have the chamfered-ſtile leſs than the pivot-poſt, and the rails to diminiſh gradually; and others ſay that the gates ſhould be ſtronger below than above, on account that the preſſure of the water is the greateſt there; but as the gates are ſupported below by the hurters, that diminution ought rather to begin at about one third of the height diſtant from the bottom. However, we ſhall ſuppoſe the pieces of the principal frame to be of the ſame dimenſions, which are as follows. In all ſluices from 8 to 12 feet wide, the pieces of the principal frames are to be 8 inches thick, and 10 broad; the intermediate rails 6 by 8; the braces and monions 4 by 6; and the whole covered with two-inch thick planks as well as all the gates of ſluices under 37 feet wide.

In ſluices which are from 13 to 18 feet wide, the pieces of the principal frame are to be 10 by 12 inches; the intermediate rails 8 by 10; the braces and monions

4 by 6. In ſluices from 19 to 24 feet wide, the pieces of the principal frame are to be 12 by 14 inches; the intermediate rails 10 by 12; the braces and monions 5 by 7. In ſluices from 25 to 30 feet wide; the pieces of the principal frame are to be 14 by 16; the intermediate rails 12 by 13; the braces and monions 6 by 8. In ſluices from 31 to 36 feet wide; the pieces of the principal frame are to be 15 by 17 inches; the intermediate rails 13 by 14; the braces and monions 7 by 9. It muſt be obſerved, that when the gates are very high, the middle rail is made of the ſame dimenſions as thoſe in the principal frame.

In all ſluices from 37 to 42 feet wide, the pieces of the principal frame are to be 16 by 18 inches; the intermediate rails 14 by 16; the braces and monions 7 by 9; and covered by planks of two inches and a half thick; or rather with two rows of planks of that thickneſs, in order that the ſeams of the under row may be covered by the upper one. Laſtly, in all ſluices which are from 42 to 48 feet wide, the pieces of the principal frame are to be 18 by 20 inches; the intermediate rails 15 by 18; the braces and monions 8 by 10; covered by planks of two inches and a half thick as before.

It may be obſerved, that theſe dimenſions depend on the width of the ſluice only; the depth of the water has not been conſidered, though it ſhould have been done; ſince the greater that depth is, the preſſure is likewiſe the greater, when the reſt is the ſame; conſequently the dimenſions here given muſt be increaſed in great depths, and diminiſhed in ſmall ones.

As to the number and ſtrength of the irons in the gates of a ſluice, they ought to be in proportion to the largeneſs and weight of the frame; the principal ones in ſmall ſluices are reduced to two ſtraps, which ſerve to bind the under and upper rails to the pivot-poſt, which they embrace on both ſides; they are let into the wood, ſo as to be even with the ſurface of the gate, and faſtened with 5 or 6 iron bolts riveted with burrs, or with rings and keys ; theſe ſtraps ought to be about one third of the width of the gate. Sometimes the chamfered-ſtile is bound to the rails above and below, with ſtrait ſtraps like the former, but oftener with bent ones, ſuch as are repreſented in the ſection, one on each ſide, bolted together in the ſame manner as the former.

When the gates belong to a large ſluice which contains a great depth of water, the middle rail is likewiſe bound to the pivot-poſt, and the chamfered-ſtile by two ſtraps in the form of a T, both within and without, bolted together as before; and when the gates are very large, two ſtraps are uſed to faſten the upper rail to the pivot-poſt, becauſe the greateſt ſtreſs lies in that part; and to ſecure it ſtill more, another ſtrap is bolted upon the edge of the upper rail, and bent againſt the pivot-poſt; this laſt ſtrap is of greater uſe to keep the gate from ſinking than any other, for which reaſon, it is ſeldom omitted, whether the gates be ſmall or large.

The various contrivances that are made to open and ſhut the gates, require ſome notice to be taken of them; but as in ſo ſmall a work as this, it is not poſſible to give a compleat deſcription of every particular part; they therefore muſt be left to the ſagacity and prudence of the builder. It muſt be obſerved, that as the wickets are made to let the water into the chamber before the gates are opened, in order to eaſe them from the great preſſure of the water on the outſide; there ſeems to be no reaſon for placing them ſo low, nor ſo far from the pivot-poſt as is commonly done; for provided they are low enough to let in ſo much water as will riſe to the ſame level within as it is without, it will be ſufficient; conſequently the lower part of the wickets ſhould never be below the middle height of the water without, whereby the weight of the irons will be diminiſhed. And the nearer the wickets are to the pivot-poſts, the leſs the preſſure would be upon the gates, when the wickets are to be opened; beſides, all poſſible means ſhould be uſed, to lighten the farther end of the gates, to prevent their ſinking, which they will do nevertheleſs, eſpecially when they are large: this however may be remedied, by placing braſs-caſters under them, at about two thirds of their width from the pivot-poſt; but then a piece of timber muſt be placed upon the floor, of a circular form, for the roller or caſter to move upon.

Sometimes the gates of large ſluices are made in the form of a part of a cylindric ſurface, whoſe baſe is a twelfth part of a circle; this is done in view to ſtrengthen the gates againſt the preſſure of the water; in ſuch a caſe the curve of the rails muſt be natural, and according to the grain of the wood, otherwiſe the gates will become weaker inſtead of being ſtronger; ſince a ſcantling cut acroſs the grain of the wood will always be weaker than any other of the ſame dimenſions, and the ſame kind of timber.

Various methods are uſed to ſhut ſluices under twenty four feet wide: in ſluices from ten to fifteen feet wide, a ſingle gate is made, which is ſometimes opened by means of a capſtane; at others the upper rail of the gate is made ſo as to go beyond the pivot-poſt, and from thence made much thicker and heavier, to be a kind of a counter-balance to the gate; the end of which being preſſed downwards by ſeveral people, and then turned round, opens the gate eaſily.

Sometimes ſingle gates are uſed of a much larger ſize than the former; theſe gates have their pivot-poſt nearly in the middle; ſo that the largeſt part of it turns towards the ſtream when the gate is to be opened, and the leaſt the contrary way. The pivot-poſt muſt be placed in ſuch a manner, that the preſſure of the water againſt the largeſt part may keep the gate ſhut cloſe, and at the ſame time that there may not be too great difficulty to open it. It has been found by experience, that when the preſſure againſt the largeſt part exceeds that againſt the leſſer, by one ſixth part, it is ſufficient; whence it is eaſily proved from the known principles of hydroſtatics, that if the width of the ſmalleſt part is to the width of the largeſt, in the proportion of 12 to 13, it will anſwer the ſaid proportion of the preſſure.

Theſe gates are certainly the moſt convenient that can be; but as there muſt be laid a ſtrong timber acroſs the ſluice to ſupport the upper pivot, no veſſels that have maſts can paſs through them; for which reaſon, they cannot be uſed but in ſluices that ſerve to keep up the water for raiſing an inundation, or in thoſe that are built at the entrance of a canal, which runs into a harbour, for the ſake of clearing and carrying away the ſand and ſhingle that have been driven in by the tides.

Wickets have been made in this manner, and found very convenient; becauſe the great preſſure of the water againſt the common ſort, makes their opening very troubleſome; whereas this ſort are opened and ſhut with great eaſe, and very little labour.

Sometimes ſluices are made in fortreſſes at the ſide of ſtone-bridges; this is done by making the piers to project beyond the bridge, and in the projected part culliſes are contrived ſo as to let down ſquare timbers, which being kept cloſe and tight, the water may be raiſed to any height: in ſhort, many other ſorts of ſluices are made upon various occaſions, which it would be inconvenient to mention in this work.

Of AQUEDUCTS.

The intent of aqueducts is generally to bring water from a ſpring or river to a town, but they are likewiſe uſed to carry canals over low ground, and over brooks or ſmall rivers: they are built with arches like a bridge, only not ſo wide, and are covered above by an arch to prevent duſt or dirt from being thrown into the water. The ancient *Romans* were remarkably curious in theſe ſorts of works, for they not only ſupplied all the parts of *Rome* with water for common uſes, but likewiſe for a great number of public baths; and that nothing might be wanting, created a public magiſtrate, whoſe only buſineſs was to take care of them, either to repair thoſe already made, or to conſtruct new ones where they were wanted; ſometimes the ſame work ſerved for both a bridge and aqueduct; then the water was led through two covered canals, one on each ſide of the road for carriages.

As theſe kinds of aqueducts differ very little in their conſtruction from common bridges, of which we have treated before, we ſhall not enter into any particulars here concerning them; but when a canal is to paſs through a country croſſed by rivers, it muſt be obſerved how high, in reſpect to the bottom of the canal, the water riſes at the time of its greateſt flood, in order to know whether theſe waters can be carried under the bottom of the canal by means of aqueducts, and have yet a ſufficient declivity to run off.

The ſame thing is to be obſerved in regard to thoſe ariſing from the rains and the melting of the ſnows, which when led into a ditch made along the higheſt ſide of the canal, may from thence be carried off to the other ſide underneath the canal: Theſe waters ſhould never be carried into the canal, unleſs it be impracticable to do otherwiſe.

It requires great precaution, as well as circumſpection, in determining the place of aqueducts, ſo as to give them ſufficient room when they have but one paſſage, which is to be widened at the entrance, and at the outlet in a proper manner: if there be not a ſufficient depth to conſtruct one of ſuch a bigneſs, as the quantity of water that is to paſs requires, two or more paſſages muſt be made at the ſide of each other, to prevent an inundation, that otherwiſe might enſue; but it muſt be obſerved, to make them in ſuch a manner as to be eaſily cleared from the ſand and mud depoſited there by the water, for want of its having a ſufficient velocity.

Therefore, when the water on both ſides is nearly level with that in the canal, it muſt be avoided as much as poſſible,